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Technical work: guidance on how to assess the possible impact of climate change on the work of the Committee

Revised draft guidance on how to assess the possible impact of climate change on the work of the Persistent Organic Pollutants Review Committee

Note by the Secretariat

As indicated in document UNEP/POPS/POPRC.9/10, the revised draft guidance on how to assess the possible impact of climate change on the work of the Persistent Organic Pollutants Review Committee is set out in the annex to the present note. The revised draft guidance is presented as submitted by the intersessional working group and has not been formally edited.

* UNEP/POPS/POPRC.9/1.

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Annex

Draft guidance on how to assess the possible impact of climate change on the work of the Persistent Organic Pollutants Review Committee

Revised draft

August 2013

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Executive summary

Background

1. To support informed decision making, the Secretariat of the Stockholm Convention, in collaboration with the Arctic Council's Arctic Monitoring Assessment Program (AMAP) have prepared a systematic and authoritative global review of the impacts of climate change on the dynamics and toxicity of persistent organic pollutants (POPs) (UNEP/AMAP, 2011). The Conference of the Parties (COP) decided to forward the outcome of the review to the POPs Review Committee (POPRC) to consider the possible implications of the interlinkages between climate change and POPs for the Committee's work. The POPs Review Committee concluded at its seventh meeting that a better understanding of the interlinkages between POPs and climate change is relevant for the work of the Committee and decided to establish an ad hoc working group in order to develop guidance on how to consider the possible impact of climate change on its work. This was decided to be based on the review prepared by the UNEP/AMAP expert group (UNEP/AMAP, 2011) and other relevant literature. Climate change impacts on and interactions with contaminants and biota are predicted by the UNEP/AMAP expert group (2011), which based their projections on the findings of climate change in the fourth report by the Intergovernmental panel on climate change (IPCC), observations in the field and experimental studies described in peer-reviewed scientific literature.

The findings in the review of climate change interactions with POPs (UNEP/AMAP 2011)

2. The key findings by the UNEP/AMAP expert group (2011) most relevant for the POPRC review of new POPs are the following:

3. Climate change is predicted to alter environmental distribution of contaminants due to changes in environmental transport, partitioning, carbon pathways, accumulation and degradation process rates, as well as their bioavailability and organisms' susceptibility to hazardous substances.

4. POPs are predicted to interact with physiological, behavioral and ecological adaptations to climate change, and thereby influence the ability of organisms, populations, communities and ecosystems to withstand and/or adapt adequately to climate change.

5. The importance of considering multiple stressors, when evaluating the risk of hazardous substances, including climate change is highlighted by the UNEP/AMAP expert group. Several findings from the Arctic show that the vulnerability of organisms to POPs depends on multiple stress factors, including exposure to multiple hazardous substances and climate change related effects. This highlights the importance of careful scientific considerations of all environmental stress factors, including toxicological interactions and climate change impacts in the hazard assessment in the risk profile.

6. They call the attention to the importance to explore and assess opportunities for co-benefits and mitigation measures to reduce emissions of greenhouse gasses and POPs. This could be done through considerations of appropriate life-cycle management options and relevant regulations.

7. They conclude that there is a need to promote an approach to identify and address the combined effects of climate change and exposure to POPs. In doing so, an exchange of information between POPRC and IPCC is needed to provide important data and facilitate the assessment of combined effects of POPs and climate change.

Conclusions by the POP Review Committee

8. Climate change interactions with POPs may have direct bearing on the Committee's work - it may influence what type of data that should be considered in the evaluation process, considerations of observed effects and levels in the environment, evaluation of possible mitigation activities, the level and reasons for concern as well as the Committee's conclusions and recommendations.

9. The approach in the evaluation of interactions between the chemical under review and climate change can be based on the systematically narrative review and methodology used by POPRC at present. In addition to this background document a simplified approach with a step by step guidance are developed for guidance. There will be no need for developing other special tools or models.

10. In the evaluation of new POPs in the screening stage (Annex D) and in the risk profile (Annex E), scientific data with given uncertainties for the specific chemical under evaluation is usually used. However, since data on the impacts of climate change on chemicals is limited, consideration should be given to data on analogous substances where the scientific evidence is adequate. In the review process uncertainties and ranges of change in physicochemical and biological processes related to climate change impacts will be handled along with the scientific approach used by the Committee.

11. The uncertainties and ranges of climate change impacts will be different for every substance, impact, scientific test/observation and region. Quantifications of the various possible effects and uncertainties in the scientific findings should be evaluated chemical by chemical and based on documented scientific findings presented. The evaluation of uncertainties or ranges of change in physiochemical, biological and ecological expressions of chemicals

related to climate change impacts will not be different from an evaluation of uncertainties and ranges in other data presented to POPRC. Theycan be included in the evaluation, in a weight-of-evidence approach, and in an integrative and balanced manner as has been the practice of POPRC in the past.

12. Based on the findings by IPCC and in the UNEP/AMAP (2011) report, climate change impacts and interactions with contaminants is particularly relevant for the risk profile (Annex E) and risk management evaluation (Annex F). Even if documented data on climate change interactions is relevant in the screening stage (Annex D), it will not be possible to fully develop on this issue at this stage. In Annex F, the criterion on "movement towards sustainable development" (c (v) in Annex F) captures the considerations of mitigation activities for the new POP and impacts on greenhouse gas emissions. There are, however, no parameters in the criteria in Annex E that clearly address climate change interactions with POPs.

13. Climate change impacts in a real-life exposure scenario can affect and modulate physicochemical and biological processes and thereby impact parameters, such as releases of contaminants and their degradation in the environment, transport and fate of contaminants in the environment, accumulation of levels of contaminants in organisms, their bioavailability to organisms, and vulnerability of organisms to the contaminants. Thus, climate change may impact the long-range transport and environmental impacts, as well as the conditional expression of physicochemical properties, persistence, bioaccumulation and toxicity of hazardous substances. The findings of observed and predicted climate change impacts and their predicted interactions with POPs will therefore be relevant to consider when presenting information on persistence, bioaccumulation, long-range transport and adverse effects in the screening phase (Annex D) of a candidate POP and in the risk profile (Annex E). Information on climate change may add to the reasons of concern, and be stated in a reason of concern according to paragraph 2 in Annex D. In the screening phase the criteria in Annex D can be used as a guidance tool to evaluate when climate change impacts may be a part of the Statement for reason of concern in the proposal to the Secretariat for listing a chemical in the Annexes A, B and/or C.

14. When the Committee considers elements related to "Hazard Assessment for the endpoints of concern" (Annex E (b)) the evaluation of the interactions between climate change and POPs will be particularly relevant. This also applies for the considerations of "environmental fate" in Annex E(c) ," which includes "data and information on the chemical and physical properties of a chemical as well as its persistence and how they are linked to its environmental transport, transfer within and between environmental compartments, degradation and transformation to other chemicals." Information on climate change and interactions with the substance under review will therefore be relevant to present in the "environmental fate" and "hazard assessment for endpoint of concern" sections in the development of the risk profile. If POPRC finds that the impacts of climate change on a given chemical adds to the concern that the use and production of that chemical poses a threat to the environment and human health and is, therefore, a critical data element for the consideration of need of global control, the Committee may highlight this information in the synthesis.

15. In specific situations, it may also be appropriate for the POPRC to consider climate change impacts when evaluating the socio-economic considerations in the risk management evaluation of a new POP (Annex F). When evaluating possible actions according to the criteria under Annex F it may thus be important to also consider the positive and/or negative impacts on society of implementing possible control measures (Annex F (c)), such as the effect on emissions of greenhouse gasses. For example, it might be appropriate to discuss climate change impacts when discussing alternatives and/or waste and disposal implications depending on the particular chemical being reviewed. If POPRC finds that the analysis of the consequences of possible control measures for energy use or greenhouse gas emissions will be of relevance for the risk management strategy this may be highlighted in the synthesis.

16. In the review of new POPs regional differences in climate change as observed and projected by IPCC should be taken into account. Climate change is predicted by the UNEP/AMAP expert group (2011) to increase the transport of POPs to the Arctic and other remote regions. Climate change is also predicted to exacerbate adverse effects of POPs in regions with increasing environmental temperatures and salinities. This will especially be of concern for subtropical and tropical regions that are experiencing elevated temperatures, increased drought and increased ocean salinities due to climate change-induced shifts in precipitation and evaporation patterns. In addition the sea level rise linked to climate change can lead to salt water intrusion into previously freshwater habitats in those regions. The extreme weather events such as flooding and heat waves that have been registered more frequently in many regions will very likely continue to become more frequent with climate change (IPCC, 2007 b). This has implications for the management of contaminated areas, stockpiles and waste.

17. To ensure that the objective to incorporate the complex climate change interaction with POPs are fully identified in all regions further efforts and guidance to enable developing countries to effectively participate in the review processes of new POPs under POPRC may be needed. This is particularly important as climate change impacts will be different in magnitude and variability in different regions and the knowledge on climate change will impact the transport and toxicity of POPs is particularly limited in developing countries. And as such, if developing countries are not assisted, some effects may go unnoticed for a fairly long time.

1. Introduction

18. Climate change induced changes in ecosystems around the world have recently been found to have an impact on the release of hazardous substances into the environment, their long-range transport (LRT) and environmental fate, and on human and environmental exposure. These climate change impacts may lead to higher health risks both for human populations and the environment from hazardous substances.

19. To support informed decision making, the Secretariat of the Stockholm Convention, in collaboration with the Arctic Council‘s Arctic Monitoring Assessment Program (AMAP) have prepared a systematic and authoritative global review of the impacts of climate change on the dynamics and toxicity of persistent organic pollutants (POPs) (UNEP/AMAP, 2011). The review of scientific findings and assessments on climate change impacts on POPs was based on comprehensive evaluation of scientific results presented in peer-reviewed literature. The review was prepared by selected distinguished international experts with extensive experience in environmental assessments and ongoing scientific research within environmental science.

20. The Conference of the Parties (COP) decided to forward the outcome of the review to the POPs Review Committee (POPRC) to consider the possible implications of the linkages between climate change and POPs for the Committee’s work on its fifth meeting in 2011 (decision SC-5/11, paragraph 14) (UNEP/POPS/POPRC.7/INF/20). The POPRC concluded at its seventh meeting that a better understanding of the interlinkages between POPs and climate change is relevant for the work of the Committee and decided to establish an ad hoc working group in order to develop guidance on how to consider the possible impact of climate change on its work. This was decided to be based on the review prepared by the UNEP/AMAP expert group (UNEP/AMAP, 2011) and other relevant literature (UNEP/POPS/POPRC.7/CRP.13/Rev.1).

21. The POPRC reviews nominated substances from Parties in three stages as described in Article 8 of the Convention using the criteria in the annexes D -F to the Convention. The initial review is a screening of the chemical properties against the criteria in Annex D. If considered fulfilled, the POPRC proceeds to the second stage and develops a risk profile according to the criteria in Annex E and the risk profile outline decided at the first meeting of the POPRC (UNEP/POPS/POPRC.1/10 /Annex IV). If the POPRC after this review decides that the substance is a POP, the POPRC prepares a risk management evaluation collecting information according to the criteria in Annex F and the outline decide at the third meeting of the POPRC (UNEP/POPS/POPRC.3/20/Annex II) to be considered by the COP.

2. Objective

22. Based on the findings made by the UNEP/AMAP expert group (2011) the interactions between climate change and POPs are found to be relevant for POPRC to consider in their evaluations of nominated substances for listing. This guidance provides an overview of the present state of knowledge on the impacts of climate change on POP's. The guideline highlights interactions between POPs and climate change that are relevant to the review processes of new POPs in POPRC. It was developed based on the predicted impacts outlined in the report by UNEP/ AMAP (2011).

23. The significance of climate change induced changes in environmental parameters for the physiochemical and ecological expression of POPs in the environment have recently been discovered, and there are still many questions to be solved. Although, the dependency of degradation, accumulation, fate, transport and adverse effects on environmental parameters is well established, and the knowledge of the climate change impacts leading to changes in environmental parameters has been known for a longer time.

24. Climate change is predicted by the UNEP/AMAP expert group to have an impact on the environmental fate of POPs and the risks they pose to the environment (UNEP/AMAP 2011). But climate change impacts on POPs are complex and a wide range of ecological and physiological processes and end points have to be taken into account. Climate change impacts in a real-life exposure scenario can affect and modulate physicochemical and biological processes and thereby impact parameters, such as the release of contaminants and their degradation in the environment, the transport and fate of contaminants in the environment, the accumulation of contaminants in organisms, their bioavailability to organisms, and the vulnerability of organisms to the contaminants. These parameters are of particular relevance to the evaluation of the environmental fate and risk of a new POP undertaken by POPRC under the criteria in Annex E. Climate change impacts on these parameters, are not predicted to change the intrinsic properties of contaminants, but may add to the global concern of use and production in the screening process of new POPs. When evaluating possible actions according to the criteria under Annex F it may be important to also consider the positive and/or negative impacts on society of implementing possible control measures, such as the effect on emissions of greenhouse gases. Thus, by affecting these parameters, climate change may have a direct bearing on the Committee's work - it may influence the type of data that should be considered in the evaluation process, considerations of observed effects and levels in the environment, evaluation of possible mitigation activities, the level and reasons for concern, as well as the Committee's conclusions and recommendations.

25. The UNEP/AMAP expert group (2011) concluded that there is a need to promote an approach to identify and address the combined effects of climate change and exposure to POPs. They identified the need for the exchange of information between POPRC and IPCC to provide important data and facilitate the assessment of the combined effects of POPs and climate change. Another objective of this document is, therefore, to provide guidance on how the POPRC may consider documented impacts of climate change on the substance under evaluation, following the criteria in annexes D, E and F in the Convention and the scientific and precautionary approach used by POPRC. In the evaluation, it is recommended that scientific data with given uncertainties for the specific chemical under evaluation is used, but that consideration can be given to data on analogous substances where scientifically defensible. In the review of new POPs regional differences in climate change as observed and projected by IPCC should be taken into account.

3. Structure and key features of the guidance

26. This guidance summarizes the predicted impacts of the interactions between POPs and climate change that were presented in the 2011 UNEP/AMAP report (UNEP/AMAP 2011). As a background to and further clarification of the 2011 UNEP/AMAP report, the guidance also provides a summary of the observed and projected climate change impacts that are relevant for the POP considerations as reported in the fourth report by IPCC in 2007 (IPCC 2007,a,b,c). In order to highlight particular findings more clearly in the text, some of the scientific studies/reviews that were referred to in the UNEP/AMAP 2011 report are cited and described separately/ independently in the guidance. In addition scientific literature databases such as ISI Web of Knowledge and PubMed have been screened for additional peer-reviewed literature. In addition relevant grey literature has been included when available. The additional studies have mainly been used to exemplify impacts that were (already) predicted by the UNEP/AMAP 2011 report. Based on this information the relevance of the predicted and observed effects for the Annex D, E and F evaluation has been investigated. The result is a guidance that highlights important elements that may be considered by the Committee when new substances for listing in the Convention are reviewed. Recommendations on how to include climate change impacts when evaluating new POPs are made. The scientific approach used by the Committee is found to be suitable when considering climate change impacts on POPs and is, for clarity, described in the guidance. The description of the approach is based on the "Handbook for effective participation in the work of the POPs review Committee.

27. The different sections of the guidance contains the following information:

Section 1 describes the background for the preparation of the guidance.

Section 2 describes the objective and approach taken in the work with the guidance.

Section 3 describes the content of the different sections of the guidance.

Section 4 describes the interactions between POPs and climate change that can be relevant to consider in the screening stage and development of a risk profile.

Section 5 describes the different stages of review of the substance, important considerations and principles in the review process, and provides a practical example on how the scientific findings on climate change impacts may be considered when evaluating a substance. The principles are based on the purpose of the Convention, the work process in the POPRC and conclusions of the elaboration of the guidance.

Section 6 provides practical guidance and tools for the data collection and evaluation and an overview table listing the information on climate change impact that can be relevant under the different stages of review.

Section 7 provides a step by step manual with the practical steps to be done when considering scientific findings on climate change impact on a substance under evaluation.

4. Interactions between POPs and climate change relevant to consider in the review processes of a new possible POP

4.1. Predicted impacts on ecosystems and POPs

28. The impacts of climate change relevant for the dynamics, behavior, fate and adverse effects of persistent organic pollutants (POPs) (UNEP/AMAP, 2011) have been evaluated and defined by the UNEP/AMAP expert group (2011) based on the fourth Assessment Report on climate change by IPCC in 2007 and a comprehensive evaluation of scientific results presented in peer-reviewed literature. The authors of the report concluded that climate change, including increasing climate variability, will affect biodiversity, and ecosystem composition, function, and vulnerability, and that climate change impacts on ecosystems and biota will interact with the fate and effects of POPs (UNEP/AMAP 2011).

29. Climate change is predicted to alter environmental distribution of contaminants due to changes in environmental transport, partitioning, carbon pathways, accumulation and degradation process rates, as well as their bioavailability and organisms' susceptibility to hazardous substances (UNEP/AMAP 2011). Furthermore, POPs are predicted to interact with physiological, behavioral and ecological adaptations to climate change, and thereby influence the ability of organisms, populations, communities and ecosystems to withstand and/or adapt adequately to climate change (UNEP/AMAP 2011; Jenssen, 2006; Wingfield, 2008).

30. Schiedek et al. (2007) have discussed and reviewed the scientific basis of interactions between climate change impacts and contaminants. They reached the same overall conclusions as the UNEP/AMAP report (2011) on effects and interactions that are relevant to consider when evaluating interactions between climate change and contaminants. Schiedek et al. (2007) developed a figure (Figure 1) to illustrate the impacts climate change is predicted to have on ecosystems and biota and how those impacts interact with contaminants' fate and effects. This figure also summarises the effects and interactions relevant to consider in the evaluations of POPs. Most of the physicochemical and biogeochemical impacts on eco-systems referred to in the figure are observed and projected changes due to climate change (IPCC 2007 a,b,c). Furthermore, an increase in UV-radiation is predicted in several reviews of climate change interactions with hazardous substances in the environment (ACIA 2005; Mac Donald et al. 2005; Wrona et al. 2006; Schiedek et al. 2007; UNEP/AMAP 2011; and references therein) and described further below in this chapter. The IPCC observed and projected climate change impacts with relevance for the behaviour, adverse effects and fate of contaminants are given in chapter 4.1 a below.

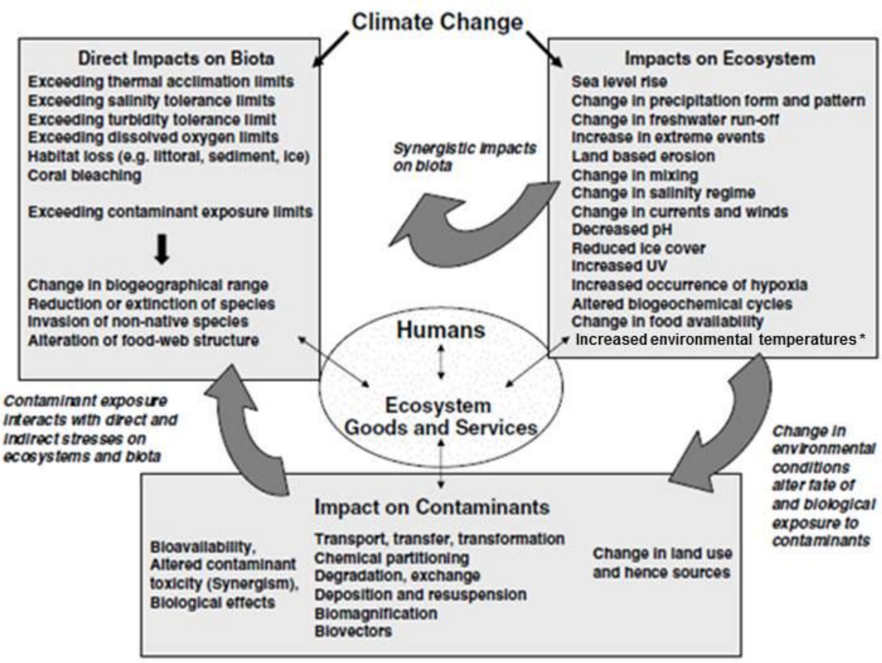

Figure 1. Overview of climate change impacts on ecosystems and biota and how they may interact with contaminants, and their fate and effects (Schiedek et al. 2007). * Increased environmental temperatures are added to the figure and were not a feature of the original figure. This effect was added to highlight this climate change impact on ecosystems, contaminants and biota, and are in accordance with (UNEP/AMAP) 2011 and Schiedek et al. (2007).

31. The prediction of an increase in UV radiation is linked to the predictions of changes in the stratosphere due to climate change and observed changes in the stratosphere and levels of ozone in the Arctic atmosphere (IPCC 2007 a; ACIA 2005). Climate change is predicted to increase the amount of UV radiation reaching the Earth's surface in the Arctic (UNEP/AMAP 2011; ACIA 2005). Observed impacts of climate changeleading to lower temperatures in the stratosphere are likely to increase the frequency and severity of stratospheric ozone-depletion in the Arctic (ACIA 2005; IPCC 2007 a). Ozone levels directly influence the amount of UV radiation reaching the surface of the earth. Climate change impact leading to reduction in snow and ice cover will increase the UV exposure of many Arctic organisms, since snow and ice cover strongly attenuate UV radiation, protecting organisms underneath. A reduction in snow and ice cover on the surface of rivers, lakes, or oceans is likely to increase the exposure of many organisms to damaging UV radiation (ACIA 2005; Wrona et al. 2006). Available individual measurements in the Arctic suggest localized increase in UV radiation levels reaching the surface, but observed time series are not yet long enough to allow trends to be detected (ACIA 2005). Reconstructed time series of surface UV radiation levels based on total column ozone, sunshine duration, and cloud cover suggest distinct increases, but reconstruction methods are less certain than direct measurements because they involve assumptions about the spectral characteristics of cloud and aerosol attenuation and surface reflectivity (ACIA 2005). Increases in UV radiation levels reaching Earth's surface have been observed to primarily occur in the spring, when ozone depletion reaches a maximum (ACIA 2005, Wrona et al. 2006). Observations have shown substantial late winter and early spring reductions in Arctic total column ozone over the last two decades (ACIA 2005). In addition loss of snow or ice cover earlier in the spring have been observed, when UV radiation is very likely to be at increased levels (ACIA 2005). Ozone levels in the stratosphere are projected to remain depleted for several decades and the surface UV radiation levels in the Arctic are therefore likely to remain elevated in the future (ACIA 2005). The elevated levels of UV radiation reaching Earth's surface are likely to be most pronounced in the spring, when ecosystems are most sensitive to harmful UV radiation years (ACIA 2005).

32. Biota are also predicted to experience increased exposure to UV-radiation in regions where a warmer climate results in a reduced cloud cover and a more arid landscape (ACIA 2005; Wrona et al. 2006). Exposure to UV radiation has been linked to skin cancers, corneal damage, cataracts, immune suppression, and aging of the skin in humans, and can also have deleterious effects on ecosystems and on materials (ACIA 2005). A major increase in UV radiation levels reaching Earth's surface would cause additional damage to organisms (biomolecular, cellular, and physiological damage, and alterations in species composition). Allocations of energy and resources by aquatic biota to UV radiation protection will increase, probably decreasing trophic-level productivity (Wrona et al. 2006). Increased UV-radiation reaching Earth's surface can interact with POPs and exacerbate the adverse effects of POPs (UNEP/AMAP 2011) as described in section 4.6 b.

(a) Observed and projected global climate change and regional differences

33. The UNEP/AMAP expert group (2011) identified the need to exchange of information between POPRC and IPCC to provide important data and facilitate an assessment of the impact of climate change on the effects of POPs. The different reviews on climate change and interactions with contaminants referred to in this report, including the report by the UNEP/AMAP expert group (2011), base their predictions on the findings by IPCC's 4th Assessment Report (2007a). IPCC prepares at regular intervals comprehensive assessment reports of scientific, technical and socio-economic information relevant for the understanding of human induced climate change, potential impacts of climate change and options for mitigation and adaptation. The most recent assessment report is from 2007 (IPCC, 2007a). On the basis of the assessment report from 2007 the IPCC concludes that observational evidence from all continents and most oceans shows that many natural systems are today being affected by regional climate changes, particularly temperature increases (IPCC, 2007b). The global assessment of data since 1970 has shown that it is likely that anthropogenic warming has had a discernible influence on many physical and biological systems (IPCC, 2007b).

34. Below the robust findings by IPCC of observed changes resulting from climate change with relevance to the interactions with POPs is listed (IPCC 2007c; UNEP/AMAP 2011}:

- Increases in global average air and ocean temperatures;
  - Observations show a trend of increasing surface, as well as lower and mid-tropospheric temperatures since 1850.
  - The average temperature of the global oceans has increased to depths of at least 3000 m since 1961.
  - The average water vapor content in the troposphere has increased since at least the 1980s over land and ocean.

- Widespread melting of snow and ice;
    - o Mountain snow cover has declined in many regions in both hemispheres.
    - o There are widespread decreases in glaciers and ice caps (Greenland and Antarctica not included).
    - o Flow speed has increased for some Greenland and Antarctica outlet glaciers, which drain ice from the interior of the ice sheets. The corresponding increased ice sheet mass loss has often followed thinning, reduction or loss of ice shelves or floating glaciers tongues.
- Rising global average sea level;
    - o Global average sea level rose at an average of 1.8 (1.3 to 2.3) mm per year from 1961 to 2003. There is *high confidence*[1] that the rate of observed sea level rise increased from the 19th to 20th century. The average global sea level rise over the 20th century is estimated to be 0.17 m
    - o Oceans have been absorbing more than 80% of the heat added to the climate system since 1961, causing sea water to expand and, therefore, contributing to sea level rise. Widespread decreases in glaciers and ice caps have contributed to sea level rise (Greenland and Antarctica not included). While losses from the ice sheets of Greenland and Antarctica have *very likely* contributed to the sea level rise over 1993 to 2003.
- Acidification of the oceans;
    - o The uptake of anthropogenic carbon since 1750 has led to the ocean becoming more acidic, with an average decrease in surface pH of 0.1 units.
- Decrease in oxygen levels in the oceans
    - o There is evidence for decreased oxygen concentrations, likely driven by reduced rates of water renewal, in the thermocline (~100–1,000 m) in most ocean basins from the early 1970s to the late 1990s.

35. IPCC (2007 b) have projected an average global warming of about 0.2°C per decade (next two decades), increasing acidification of the oceans, decreasing snow cover and widespread increases in thaw depth over most permafrost regions and increasing sea level rise. The coastal polar regions and high altitude mountainous zones is projected to experience decreased snow cover (precipitation), reduced glaciers coverage, ice caps and permafrost thawing, and is predicted to experience increased cloudiness and increased precipitation (IPCC 2007 b; ACIA 2005; Mac Donald et al. 2005). Sea ice is projected to shrink in both the Arctic and Antarctic. In some projections, Arctic late-summer sea ice disappears almost entirely by the latter part of the 21st century (IPCC 2007 b). Arctic sea ice is already considerable reduced during the summer season and is predicted to break open during the summer season within the next 30 years (ACIA 2005; AMAP (SWIPA) 2011). The Arctic will experience an increase in fresh-water run-off from melting glaciers and ice caps (IPCC 2007 b; ACIA 2005; AMAP (SWIPA 2011). Warming is projected to be greatest over land and at most high northern latitudes, and least over the Southern Ocean and parts of the North Atlantic Ocean (IPCC 2007 b). Changes in the frequency, magnitude, extent and duration of extreme events as a result of climate change are still poorly understood, and existing model projections suggest there will be significant regional variability. But IPCC states in their report that it is *very likely* that hot extremes, heat waves and heavy precipitation events will continue to become more frequent (IPCC 2007 b).

36. According to the fourth report developed by IPCC (2007 a, b, c), the result of the impact of climate change on the physical environment of ecosystems on a regional level will vary and will be expressed differently between regions (IPCC 2007, a, b, c). The interaction between climate change impacts and the conditional expression of POPs chemical and physical properties will therefore also differ between regions in some aspects. According to IPCC fourth Assessment Report it is *very likely* that all land regions will warm in the 21st Century (IPCC 2007 b), but that there will be regional differences in changes in meteorology, wind and sea current systems, precipitation form and pattern, cloudiness, extreme weather events, salinity regimes, fresh water run-off and soil erosion. Table 1 summarizes the observed and projected regional climate changes according to the IPCC (2007 b).

[1] For a detailed description of the uncertainty terminology as introduced by IPCC please refer to: IPCC, " Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties", IPCC Cross-Working Group Meeting on Consistent Treatment of Uncertainties Jasper Ridge, CA, USA. 6-7 July 2010.

Table 1. Observed and projected climate change impacts in different regions according to IPCC fourth report (IPCC 2007 b)[2].

Region	Observed	Projected
Africa	Drying has been observed in the Sahel and southern Africa. Freshening of mid-latitude waters and increased salinity in low latitude waters have been suggested. Mid-latitude westerly winds have been strengthened in both hemispheres since the 1960s. More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics. The frequency of heavy precipitation events has increased over most land areas. Widespread changes in extreme temperatures have been observed over the last 50 years.	Warming is *very likely* to be larger than the global annual mean warming throughout the continent and in all seasons, with drier subtropical regions warming more than the moister tropics. Annual rainfall is *likely* to decrease in much of Mediterranean Africa and the northern Sahara, with a greater likelihood of decreasing rainfall as the Mediterranean coast is approached. Rainfall in southern Africa is *likely* to decrease in much of the winter rainfall region and western margins. There is *likely* to be an increase in annual mean rainfall in East Africa. It is unclear how rainfall in the Sahel, the Guinean Coast and the southern Sahara will evolve.
Mediterranean and Europe	Significantly increased precipitation has been observed in northern Europe. Drying has been observed in the Mediterranean. Changes in precipitation and evaporation over the oceans are suggested by freshening of mid- and high latitude waters. Mid-latitude westerly winds have strengthened since the 1960s. More intense and longer droughts have been observed. The frequency of heavy precipitation events has increased. Widespread changes in extreme temperatures have been observed over the last 50 years.	Annual mean temperatures in Europe are *likely* to increase more than the global mean. Seasonally, the largest warming is *likely* to be in northern Europe in winter and in the Mediterranean area in summer. Minimum winter temperatures are *likely* to increase more than the average in northern Europe. Maximum summer temperatures are *likely* to increase more than the average in southern and central Europe. Annual precipitation is *very likely* to increase in most of northern Europe and decrease in most of the Mediterranean area. In central Europe, precipitation is *likely* to increase in winter but decrease in summer. Extremes of daily precipitation are *very likely* to increase in northern Europe. The annual number of precipitation days is *very likely* to decrease in the Mediterranean area. Risk of summer drought is *likely* to increase in central Europe and in the Mediterranean area. The duration of the snow season is *very likely* to shorten, and snow depth is *likely* to decrease in most of Europe.
Asia	Significantly increased precipitation has been observed in northern and central Asia. Drying has been observed in parts of southern Asia. Changes in precipitation and evaporation over the oceans are suggested by freshening of mid- and high latitude waters together with increased salinity in low latitude waters. Mid-latitude westerly winds have strengthened in both hemispheres since the 1960s. More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics. The frequency of heavy precipitation events has increased over most land areas. Widespread changes in extreme temperatures have been	Warming is *likely* to be well above the global mean in central Asia, the Tibetan Plateau and northern Asia, above the global mean in eastern Asia and South Asia, and similar to the global mean in Southeast Asia. Precipitation in boreal winter is *very likely* to increase in northern Asia and the Tibetan Plateau, and *likely* to increase in eastern Asia and the southern parts of Southeast Asia. Precipitation in summer is *likely* to increase in northern Asia, East Asia, South Asia and most of Southeast Asia, but is *likely* to decrease in central Asia. It is *very likely* that heat waves/hot spells in summer will be of longer duration,

[2] Treatment of Uncertainties; see Box TS.1 in the technical summary of the fourth report by IPCC (IPCC 2007 a).

Region	Observed	Projected
	observed over the last 50 years.	more intense and more frequent in East Asia. Fewer very cold days are *very likely* in East Asia and South Asia. There is *very likely* to be an increase in the frequency of intense precipitation events in parts of South Asia, and in East Asia. Extreme rainfall and winds associated with tropical cyclones are *likely* to increase in East Asia, Southeast Asia and South Asia. Sea levels are *likely* to rise on average during the century around the small islands of the Indian Ocean and northern and southern Pacific Oceans. Annual rainfall is *likely* to increase in the northern Indian Ocean with increases *likely* in the vicinity of the Seychelles in December, January and February, and in the vicinity of the Maldives in June, July and August, while decreases are *likely* in the vicinity of Mauritius in June, July and August. Annual rainfall is *likely* to increase in the equatorial Pacific, while decreases are projected by most models for just east of French Polynesia in December, January and February.
North America	Significantly increased precipitation has been observed in eastern parts of North America. Changes in precipitation and evaporation over the oceans are suggested by freshening of mid- and high-latitude waters together with increased salinity in low latitude waters. Mid-latitude westerly winds have strengthened since the 1960s. More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics. The frequency of heavy precipitation events has increased over most land areas. Widespread changes in extreme temperatures have been observed over the last 50 years. There is observational evidence for an increase in intense tropical cyclone activity in the North Atlantic since about 1970, correlated with increases of tropical sea surface temperatures.	The annual mean warming is *likely* to exceed the global mean warming in most areas. Seasonally, warming is *likely* to be largest in winter in northern regions and in summer in the southwest. Minimum winter temperatures are *likely* to increase more than the average in northern North America. Maximum summer temperatures are *likely* to increase more than the average in the southwest. Annual mean precipitation is *very likely* to increase in Canada and the northeast USA, and *likely* to decrease in the southwest. In southern Canada, precipitation is *likely* to increase in winter and spring but decrease in summer. Snow season length and snow depth are *very likely* to decrease in most of North America except in the northernmost part of Canada where maximum snow depth is *likely* to increase.
Central and South America	Significantly increased precipitation has been observed in eastern parts of North and South America. Changes in precipitation and evaporation over the oceans are suggested by freshening of mid- and high-latitude waters together with increased salinity in low latitude waters. Mid-latitude westerly winds have strengthened since the 1960s. More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics. The frequency of heavy precipitation events has increased over	The annual mean warming is *likely* to be similar to the global mean warming in southern South America but larger than the global mean warming in the rest of the area. Annual precipitation is *likely* to decrease in most of Central America and in the southern Andes, although changes in atmospheric circulation may induce large local variability in precipitation response in mountainous areas. Winter precipitation in Tierra del Fuego and summer precipitation in south-eastern South America is *likely* to

Region	Observed	Projected
	most land areas. Widespread changes in extreme temperatures have been observed over the last 50 years. There is observational evidence for an increase in intense tropical cyclone activity in the North Atlantic since about 1970, correlated with increases of tropical sea surface temperatures.	increase. It is uncertain how annual and seasonal mean rainfall will change over northern South America, including the Amazon forest. However, there is qualitative consistency among the simulations in some areas (rainfall increasing in Ecuador and northern Peru, and decreasing at the northern tip of the continent and in southern northeast Brazil). Sea levels are *likely* to rise on average during the century around the small islands of the Caribbean Sea. Summer rainfall in the Caribbean is *likely* to decrease in the vicinity of the Greater Antilles but changes elsewhere and in winter are uncertain.
Australia and New Zealand	Changes in precipitation and evaporation over the oceans are suggested by mid- and high-latitude waters. Mid-latitude westerly winds have strengthened since the 1960s. More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the subtropics. The frequency of heavy precipitation events has increased over most land areas. Widespread changes in extreme temperatures have been observed over the last 50 years.	Warming is *likely* to be larger than that of the surrounding oceans, but comparable to the global mean. The warming is less in the south, especially in winter, with the warming in the South Island of New Zealand *likely* to remain less than the global mean. Precipitation is *likely* to decrease in southern Australia in winter and spring. Precipitation is *very likely* to decrease in south-western Australia in winter. Precipitation is *likely* to increase in the west of the South Island of New Zealand. Changes in rainfall in northern and central Australia are uncertain. Increased mean wind speed is *likely* across the South Island of New Zealand, particularly in winter. Increased frequency of extreme high daily temperatures in Australia and New Zealand, and a decrease in the frequency of cold extremes is *very likely*. Extremes of daily precipitation are *very likely* to increase, except possibly in areas of significant decrease in mean rainfall (southern Australia in winter and spring). Increased risk of drought in southern areas of Australia is *likely*.
Polar regions	Average arctic temperatures increased at almost twice the global average rate in the past 100 years. Satellite data since 1978 show that annual average arctic sea ice extent has shrunk by 2.7 [2.1 to 3.3]% per decade, with larger decreases in summer of 7.4 [5.0 to 9.8]% per decade. Temperatures at the top of the permafrost layer have generally increased since the 1980s in the Arctic (by up to 3°C). The maximum area covered by seasonally frozen ground has decreased by about 7% in the Northern Hemisphere since 1900, with a decrease in spring of up to 15%.	The Arctic is *very likely* to warm during this century more than the global mean. Warming is projected to be largest in winter and smallest in summer. Annual arctic precipitation is *very likely* to increase. It is *very likely* that the relative precipitation increase will be largest in winter and smallest in summer. Arctic sea ice is *very likely* to decrease in its extent and thickness. It is uncertain how the Arctic Ocean circulation will change. The Antarctic is *likely* to warm and the precipitation is *likely* to increase over the continent. It is uncertain to what extent the frequency of extreme temperature and precipitation events will change in the polar regions.

37. In the IPCC's 4th Assessment Report (2007 b), increases in global average temperature exceeding 1.5-2.5°C and the levels of atmospheric carbon dioxide that would drive such a temperature change are projected to lead to major changes in ecosystem structure and function, species' ecological interactions, and species' geographical ranges, with predominantly negative consequences for biodiversity, and ecosystem goods and services e.g., water and food supply (IPCC, 2007b).

(b) Impact on marine ecosystems

38. Recent reviews indicates that rising greenhouse gas concentrations in the atmosphere can have a significant impact on marine ecosystems in the ocean waters, causing a decrease in ocean productivity, altering food web dynamics, reducing the abundance of habitat-forming species, shifting species distributions, and causing a greater incidence of disease (Hoegh-Guldberg and Bruno 2010; Doney et al. 2012; OECD 2004; Saber 2009).

39. The increased heat and sunlight altering salinity levels, nutrient supply, stratification of waters and the depth of light penetration in the open ocean seawater is likely to have an impact on phytoplankton abundance (UNEP/AMAP 2011; Behrenfeld et al. 2006; Boyce et al. 2010). According to Behrenfeld et al. (2006) there is an inverse relationship between ocean productivity and increasing temperatures. By comparing sea surface satellite monitoring of phytoplankton abundance from 1998-2004, they found a corresponding inverse relationship between stratification strength and oceanic primary productivity. The author's comparisons of temperature changes at the sea surface and modeled net primary productivity changes for this period revealed the anticipated inverse relationship of increasing temperatures coupled to decreasing production. They concluded that observed reductions in ocean productivity during the recent post-1999 warming period provide insight on how future climate change can alter marine food webs. The way that primary productivity will react to climate change is complex and expected to vary significantly on regional scales depending on the changes in chemical and physical parameters in a given region (UNEP/AMAP 2011).

40. A strong stratification may decrease the mineralisation processes, altering the water/sediment distribution and keep the particle-bound contaminants in the upper water column, increasing their surface transport (Parsons et al. 1984). Wind speeds have generally increased over the oceans in the last 30 years according to Fox et al. (2009) but the effect on ocean currents are uncertain. The wind patterns have been strengthened in mid latitude regions in both hemispheres (IPCC, 2007a, b, c).

41. The observed sea level rise linked to climate change is projected to lead to salt water intrusion into previously freshwater habitats (IPCC, 2007b). However, salinity could decrease in waters receiving elevated inputs of freshwater due to an increase in precipitation or snow and ice melt. In sum, the effects of climate change on salinity pattern are complex and may vary between regions, as a number of factors can influence this parameter. Climate change is predicted to cause shifts in regional precipitation and evaporation patterns, terrestrial freshwater run-off and ice melt and will thus cause alteration in the salinity of the sea (IPCC, 2007a). A salinity decrease is expected in the Arctic due to ice melt in the central Arctic Ocean (AMAP 2011). Climate change induced increases in salinity in subtropical and tropical oceans and freshening of mid and high latitude waters has already been observed (IPCC, 2007b). Alterations in salinity can affect the exposure, degradation, and bioavailability of POPs as described in chapter 4.

42. Owing to increasing levels of carbon dioxide (CO2) in the marine environment, ocean acidification is an expected outcome of climate change (Hoegh-Guldberg and Bruno, 2010; Haugan and Drange, 1996) and have already been observed according to IPCC (2007 b). This trend is also projected to increase with climate change; reductions in average global surface ocean of pH is projected to lie between 0.14 and 0.35 units over the 21st century, adding to the present decrease of 0.1 units since pre-industrial times (IPCC 2007 b)). This can have an impact on POPs as described in chapter 4.6 b. A growing body of evidence demonstrates that ocean acidification can impact the survival, growth, development and physiology of marine invertebrates (Dupont et al. 2012a). Many marine species predicted to be sensitive to this stressor are photosymbiotic, including corals and foraminifera (Dupont et al. 2012b). Expected reductions in the pH of seawater may have consequences for marine life, but there are only a few studies describing how pH interacts (UNEP/AMAP 2011) with the toxicity of POPs, and no clear relationships between ocean acidification and POPs toxicity have been described so far (UNEP/AMAP 2011).

43. According to reviews by Diaz and Rosenberg (2001) and Schiedek et al. (2007) areas affected by anoxia and hypoxia in aquatic ecosystems worldwide have generally expanded, and have become more frequent in recent decades (Diaz and Rosenberg, 2001; Schiedek et al. 2007; and references therein). This trend will probably continue with climate change (Schiedek et al., 2007; and references therein). Global warming is predicted to increase the problem of hypoxia due to increased precipitation and temperatures bringing nutrient-rich, fresh and relatively warm water to sensitive areas where water stratification will increase (Harley et al. 2006). Factors such as eutrophication and higher water temperature are predicted to cause a reduction in the oxygen content in water (UNEP/AMAP 2011; and references therein). The types of areas usually exposed to hypoxia events are coastal areas, near shore areas, estuarine and upwelling areas (Diaz and Rosenberg 2001; Schiedek et al. 2007; Harley et al., 2006). In many coastal areas or estuaries, hypoxia is a common feature during low tide and species living there have successfully adapted to cope with

low oxygen conditions, but with increasing temperature many species are likely to reach their thermal acclimation limits (Schiedek et al. 2007 and references therein). The combined physiological stress imposed by hypoxia and the toxic effect of POPs can exacerbate the adverse effects of both (UNEP/AMAP 2011) as described in 4.6 b.

(c) Multiple stressors and vulnerable species and populations

44. Many scientific reviews highlight the importance of considering multiple stressors, when evaluating the risk of hazardous substances, including climate change (Letcher et al 2010; Schiedek et al. 2007; UNEP/AMAP 2011; Noyes et al. 2009; ACIA 2005).

45. Climate change and climate variability act as factors which can influence the general health or exposure of animal and human populations making them more vulnerable for POP exposure (Sciedek et al. 2007; Noyes et al. 2009; UNEP/AMAP 2011; and references therein). Factors of relevance in this aspect are additional heat stress, colder climates, more or less rainfall, food availability and quality, availability of services and shelter, movements of disease-bearing insect vectors, bioavailability of toxicants and their possible enhanced toxicity (Sciedek et al. 2007; Noyes et al. 2009; UNEP/AMAP 2011; and references therein).

46. POPs are predicted to interfere with physiological, behavioural and ecological adaptations to climate change, and thereby influence the ability of organisms, populations, communities and ecosystems to withstand and/or adapt adequately to climate change (UNEP/AMAP 2011; Jenssen, 2006; Wingfield, 2003 and 2008; Colborn, 1995; Zala and Penn, 2004; Heugens et al., 2002; Noyes et al., 2009;).

47. According to the review by Wingfield et al. (2008) climate change together with human disturbance such as habitat invasion/ loss imposes stress on wild organisms and to survive the organisms have to be flexible and adapt. Climate change may interfere with environmental variables such as temperature that regulate and time important events in their life cycle. Because of these changes, the possibility exists that some species may become asynchronous with environmental conditions conducive for breeding, migrating or molting (Wingfield et al. 2008). While there is evidence that some species may have the plasticity to respond and develop new life history stages within a few generations, species/ populations that do not have sufficiently flexible (neuroendocrine and endocrine) control systems to be able to change their life-cycle histories may however, because they fail to adapt, experience loss in reproductive success with potential secondary effects such as population decline and extinction (Wingfield et al. 2008). In addition to interfering with the environmental cues global change may result in, other and more unpredictable perturbations in the environment such as decreased rainy seasons, less ice-cover etc. Such perturbations of the organisms' physical environment may also, like changes in environmental variables and lack of flexibility, impact reproduction and survival. The added effect of the two may ultimately prove detrimental to the populations'/ species' survival (Wingfield et al. 2008). The key to understanding this impact lies in the neuroendocrine and endocrine control systems, which in conjunction with direct neural regulation, are the major links between the perception of environment and morphological, physiological and behavioural responses (Wingfield et al. 2008). Many POPs have adverse effects, such as immune system suppression, neurological impairment, growth retardation, altered behavioural development, reproductive effects and metabolic disorder (UNEP/AMAP 2011; and references therein), interfering with stress responses in organisms (Jenssen et al. 2006; Wingfield et al. 2003).

48. Climate change is predicted to lead to exposure of organisms to pathogens and disease vectors that they have not been previously encountered (Harvell et al., 2002), and POPs that cause immunosupression may make animals more sensitive to (Acevedo-Whitehouse and Duffus, 2009) infectious disease agents (UNEP/AMAP 2011; Schiedek et al. 2007).

49. Furthermore, there is concern about effects arising from multiple stressors (figure. 2), including exposure to POPs and climate change, in environments where species are living at the edge of their physiological tolerance, such as in the Baltic Sea, or in polar and alpine regions (Schindler and Smol, 2006; Schiedek et al., 2007; Bustnes et al., 2008; Noyes et al., 2009; Letcher et al. 2010; UNEP/AMAP 2011; ACIA 2005). POPs with endocrine disrupting properties are adding to this concern (Kortenkamp et al. 2011, WHO/ IPCS 2002, WHO 2000), since endocrine systems are important for the ability of Arctic mammals to respond adequately and adapt to environmental stress (UNEP/AMAP 2011; Letcher et al. 2010; Jenssen 2006; ACIA 2005). Though controlled laboratory studies have documented that endocrine disruptors may affect cognitive learning, reproduction, and sexual behaviour such cause and effect relationships are harder to prove in wild organisms.

50. Recent evidence suggests that a combination of POPs and other stressors may have strong adverse effects on biota, even at low levels of POP exposure. The effects of POPs on an organism seem to be state-dependent and can be exacerbated in combination with exposure to other stressors such as predation, pathogens and food deprivation and effects induced by climate change, such as temperature increase (Relyea and Mills, 2001; Sih et al., 2004; Bustnes et al., 2006, 2008; Letcher et al. 2010).

51. Letcher et al. (2010) concludes that a great deal of caution must be exercised in establishing POP exposure level thresholds in relation to adverse effects due to multiple stressors, such as climate change, exposure of biota to a range of contaminants and the toxicological interactions between them, temporal and geographical trends in POP

exposure, differing sensitivity to POPs during an organism's life cycle, differences between species sensitivity, differences between captive laboratory model animals and wild animals, etc.

52. Many Arctic top predators have seasonal starving periods (AMAP 2003) or are hibernating (ACIA 2005) connected to winter periods with scarcity of food (sea mammals and terrestrial mammals) and breeding seasons in the spring (arctic birds), making them more sensitive to additional stressors. Female common eiders (Somateria mollissima) starve during the nesting stage and may lose 30–45% of their initial body mass, mostly through lipid mobilization (Bustnes et al. 2010a). Bustnes et al. (2010a) studied the effects of fasting on the blood concentrations of three lipid-soluble organochlorines (OCs); polychlorinated biphenyl [PCB]-153; 1-dichloro-2,2-bis (p-chlorophenyl) ethylene [p,p0-DDE]; and hexachlorobenzene [HCB]). The authors concluded that although the absolute levels of OCs in eiders were relatively low their rapid build-up in the blood during incubation was of concern as it coincided with poor body condition and weakened immune systems in the common eider population. A similar correlation was found by Sagerup et al. (2009) in his study of dying and dead Arctic glaucous gulls between emaciation and elevation of levels of a range of POPs in vital lipid rich internal organs (brain and liver). The many incidents of dying gulls during the breeding season have been studied in a period of 30 years (Bogan and Bourne, 1972; Gabrielsen et al., 1995).

53. A key result from many model prediction is that a changing climate will lead to structural changes in composition of species within ecosystems (Callaghan et al., 2004; Ims and Fuglei, 2005; Letcher et al. 2010). This will result in changes in prey availability for predators, which may influence both the accumulation and effects of POPs (Letcher et al. 2010). Some top predators have been observed to undergo periods of enforced fasting related to climate change (UNEP/AMAP 2011; ACIA 2005; AMAP 2003; Cherry et al., 2009). Longer periods of starvation due to changes in ice cover would lead to higher internal exposure of POPs released from fat reserves. For instance, over the past two decades, it has been shown that increasingly earlier breakup of the Arctic sea ice has been linked to lower body condition, birth and survival rates in Western Hudson Bay polar bears (Regehr et al., 2007; Stirling et al., 1999; Letcher et al., 2010). The impacts of climate change on polar bears may also be a dynamic factor in the type, complexity and level of organohalogen compounds (OHC) exposure, and subsequently on OHC-related effects (Letcher et al. 2010). For example, in the study by McKinney et al. (2009) it was found that temporal diet variation (shift in prey seal species) (1991 to 2007) in polar bears from the Western Hudson Bay subpopulation was related to changes in the timing of the annual sea ice breakup, and was linked to increases in the tissue concentrations of several OHCs (McKinney et al., 2009; Letcher et al. 2010).

54. Several arctic animals, especially top predators are considered endangered and are on the IUCN Red List of Threatened Species (www.iucnredlist.org) and Letcher et al. (2010) have identified several “hot spot” species and populations suffering from OHC exposure and effects in the Arctic (figure 2). They are already experiencing exposure to high levels of a cocktail of hazardous substances, due to long range transport (LRT), which when coupled with other climate change induced stress, lead to declining populations (Letcher et al. 2010).

55. Concern about contaminants, changing cultural values, and the lack of availability of traditionally-hunted species due to climate change, all play a role in influencing the types of traditional/local foods consumed, the frequency of their consumption, and the exposure of Arctic populations to POPs (UNEP/2011; and references therein). The Arctic human population may experience an increase in their exposure to POPs due to climate change but to predict the effect is very difficult due to the complexity of change in the Arctic ecosystem (AMAP 2011). Adding to the complexity of an assessment of the effects of contaminants on human populations is that environmental exposures are always to mixtures of POPs and metals because they co-occur in the food. How the contaminants interact (antagonistically, additively, or synergistically) will be affected by the health status of the population and the stress of the individual’s experience (AMAP 2011). These stress factors are related to socio-economic status, education, availability of health care, community cohesion, alcohol and tobacco consumption, etc. These types of stressors, often referred to as determinants of health, can be affected directly by climate change and climate variability (heat/cold stress, social stress, changes in types and abundance of species hunted, the influx of new diseases, less physical activity as hunting opportunities decline, etc.) (AMAP 2011).

56. Climate change is predicted to have implications for agricultural and livestock production, with consequences for food security (Miraglia et al. 2009. The review article by Miraglia et al. (2009) identified probable climate change induced impacts on agricultural and livestock production including: a reduction in overall productivity, an increase in contaminant residues due to increased remobilization and LRT, an increase in pesticide residues in plant products affected by increased pest pressure, increased mycotoxins in plant products, an increase in marine biotoxins in sea food following more frequent harmful algal blooms, and an increase in the presence of pathogens in foods following more frequent extreme weather conditions, such as flooding and heat waves (Miraglia et al. 2009; and references therein). The growth of populations of harmful pathogens, such as viruses, bacteria and protozoa, seems to be stimulated by increased water and air temperatures (Miraglia et al. 2009; and references therein). Flooding and precipitation seems to increase the dissemination of pathogenic agents waves (Miraglia et al. 2009; and references therein). Heavy rainfall and floods may increase the erosion and runoff of contaminated water with pathogens from contaminated soil and sediments into agricultural areas with plant crops (Miraglia et al. 2009; and references therein).

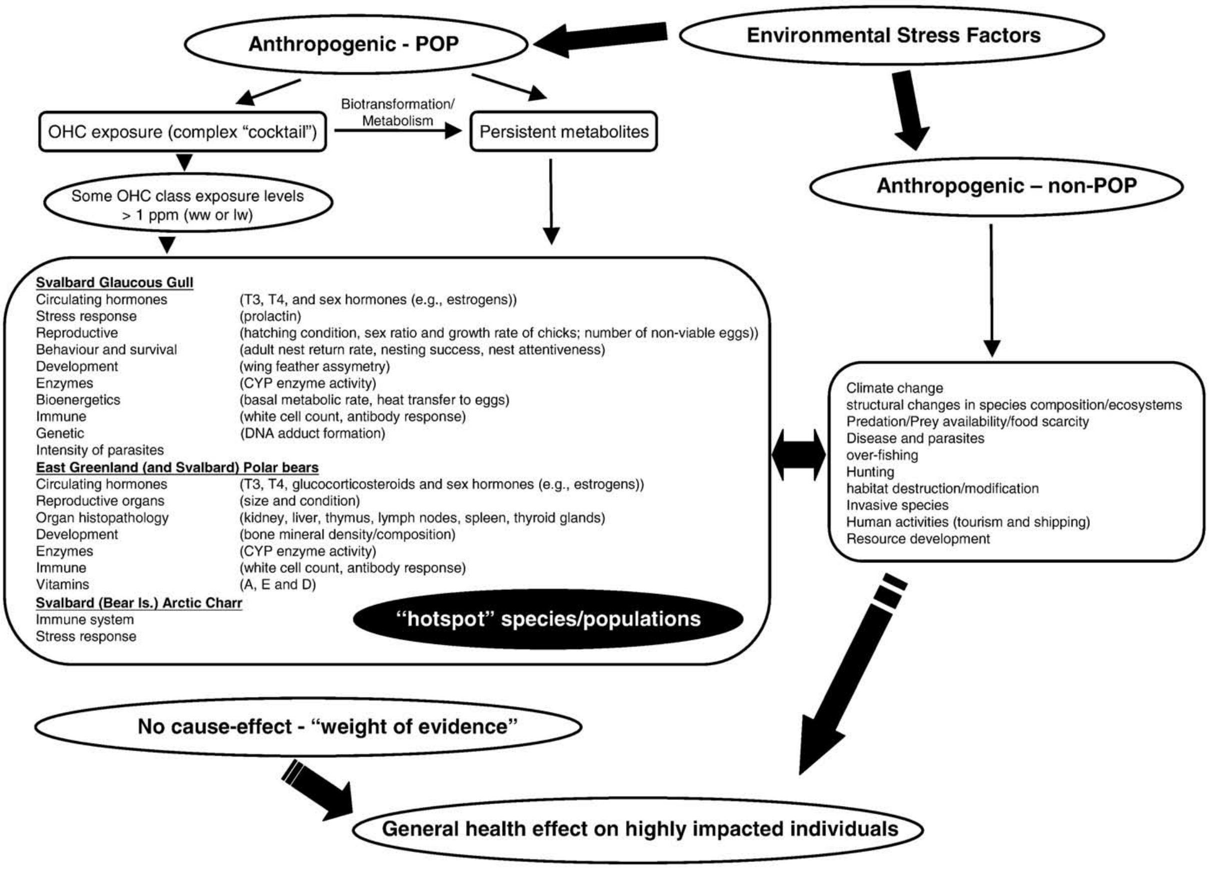

Fig. 2. Arctic species and populations ("hotspots") of concern based on "weight of evidence" of stress and effects related to OHC exposure and other stressors (Letcher et al. 2010).

4.2. Exposure

(a) Primary and secondary sources

57. Releases from secondary sources such as environmental reservoirs in soil, sediments, ice sheets and snow have been observed to be a result of climate change induced effects (Macdonald 2005; AMAP 2003; NorACIA 2009; UNEP/AMAP 2011; AMAP 2011; Ma et al. 2011; Nizetto et al. 2010; Grannas et al. 2012).

58. In the polar regions, temperate regions and mountain zones[3], climate induced effects, such as increased precipitation, permafrost thawing and reduced ice and snow cover have been observed (IPPC 2007 a, b, c). Several studies have indicated that this can lead to increased revolatilization of POPs from the sea surface to the air, transfer of POPs to the sea water due to fresh water run-off from land, soil erosion remobilising POPs to the aquatic environment and an increased deposition of particle-bound contaminants to both land and sea from the air (Blais et al. 2001; Wu et al 2010; Bogdal et al. 2010; Ma et al. 2011; Xie et al. 2011; AMAP 2011 (SWIPA); AMAP 2011). Revolatilization of POPs from reservoirs in water and soil in the Arctic has been reported, due to permafrost thawing and snow melt of the Arctic tundra (AMAP 2011; AMAP 2003; AMAP (SWIPA) 2011; IPCC 2007 a, b). Sea ice break-up and melting in the Arctic are suspected to be an important explanation for the increased levels of HCH and PCB in the air over the Arctic Ocean north of the polar circle (AMAP 2011; NorACIA 2009). Long term monitoring has detected a large increase of HCH, PCB and DDT in the melting water from Arctic glaciers (AMAP 2003; NorACIA 2009).

59. Geisz et al. (2008) indicate that the levels of DDT in penguin populations connected to the Western Antarctica Peninsula may be increasing due to the climate change impact on the local glaciers. Geisz et al. (2008) analyzed DDT in Adèlie penguin samples collected from 2004 to 2006 in Antarctica. They found an overall decline of ΣDDT (p,p´-DDT + p,p´-DDE) in the Adèlie penguin populations in Antarctica since 1964, with an exception for the Adèlie penguin population living on the Western Antarctica Peninsula where the levels increased from 1964-2006. The general decline in levels coincides with the severely restricted use worldwide since the 1970's. However, according to the authors, DDT has not declined in Ade´lie penguins from the Western Antarctic Peninsula for more

[3] Called the third pole in climate change context.

than 30 years and the presence of p,p′- DDT in these birds indicates that there is a current source of DDT to the Antarctic marine food web. DDT has been banned or severely restricted since peak use in the 1970s, implicating glacier melt water as a likely source for DDT contamination in coastal Antarctic seas (Geisz et al. 2008). The author's estimates indicate that 1-4 kg · y-1 ΣDDT are currently being released into coastal waters along the Western Antarctic Ice Sheet due to glacier ablation. The Western Antarctica ice sheet shows the highest increase in warming temperatures in the Antarctic. The West Antarctic ice sheet has warmed by more than 0.1 °C/decade in the last 50 years and show a stronger increase than other parts of the Antarctica (Steig et al. 2009). The total ice discharge from Western Antarctica Peninsula has increased 30% between 1974 and 2007, and the net mass loss increased 170% from 39 ± 15 Gt/yr to 105 ± 27 Gt/yr (Rignot 2008).

60. In addition, particle-bound contaminants are predicted by the UNEP/AMAP expert group (2011) to become more transportable in regions which are getting hotter and drier, due to wind erosion. In regions where more rainfall occurs, particle-bounded contaminants are predicted to become more transportable, due to flooding and erosion into oceans and in regions experiencing sea level rise they get more transportable because of land erosion (UNEP/AMAP 2011).

61. According to IPCC more frequent and intense extreme weather events such as heat waves, heavy precipitation, droughts and intensity of tropical cyclones have been observed in many regions as a result of global warming (IPCC, 2007; IPCC, 2012). Extreme weather events have a documented impact on the remobilization and subsequent bioavailability of POPs (Weber et al. 2008 and 2011; Holoubek et al. 2007; Presley et al. 2006; Pulkrabová et al. 2008; Heimann et al. 2011). It has been shown that local concentrations of certain POPs were elevated several fold in soils, sediments and runoff waters, shortly after hurricanes and storms due to remobilisation of contaminants in soil and sediments in the affected areas (Burgoa and Wauchope, 1995; Presley et al., 2006).

62. The findings by Holoubek et al. (2007) demonstrated the consequence of frequent extreme flood events and the possible impacts of local natural disasters from the LRT of PCBs. Data from ten years of integrated monitoring at Kosetice observatory in Czech Republic were used to assess long-term trends of POPs in the ambient air and wet deposition in the European continental background by Holoubek et al. (2007). They found that increased levels of PCBs were associated with extreme flood events. The negative trend in atmospheric PCB levels from 1996-2005 was disrupted by two periods of much higher air concentrations that correlate to the extreme flood events 1997 and 2002. During the two events, vast areas were flooded and the extreme floods were followed by extremely hot summers. PCBs were banned long ago and the variations were not connected to production facilities that were flooded or point source emissions. Therefore, the authors concluded that the increased air concentrations could only be explained by evaporation from contaminated areas that were flooded, which resulted in the remobilisation of PCBs from old reservoirs in river sediments, making them subject of atmospheric transport. Evaporation from the flooded areas was suspected to be the source of elevated atmospheric concentrations of PCBs for several years after the flood itself.

63. Some examples of extreme weather events have been described and placed in a long-term perspective that can be linked to climate change induced effects by IPCC (IPCC 2007 b). The central European floods in the summer of 1997 and 2002 were caused by heavy precipitation episodes and were followed by a heat wave in the summer of 2003. Those events were correlated with observations of maximum precipitation levels at German weather stations. The records from a majority of German weather stations have shown an increase in precipitation variability during the last century, which is, according to the IPCC, an indication of the enhanced probability of floods and droughts in the region (IPCC 2007 b).

64. To investigate the extent of terrestrial contamination after the extreme floods in 2002 in the Vltava and Elbe basins, major rivers in Central Europe, a 4-year survey was conducted by Pulkrabová et al. (2008). The extreme floods were caused by heavy and continuous precipitation in the Czech Republic and surroundings, and led to the damage of cities and towns, as well as the loss of property and human life. The survey revealed remarkably higher levels of dichlorodiphenyl trichloroethane (DDTs) in the flooded arable soil than in reference (non-flooded soil) samples. The levels of DDTs exceeded the maximum tolerable values for the sum of persistent organochlorine pesticides given by the Ministry of Environment of the Czech Republic of 100 µg/kg dry weight in the years 2003-2005. The DDT concentration in cereals grown on the flooded soil was close to limit of quantification (LOQ). The LOQ is the lowest concentration at which the analyte can be reliably detected, meeting some predefined goals for bias and imprecision. The authors did not provide the actual concentrations or if they were above or below the LOQs for cereals.

65. According to the review by Weber et al. (2008) contaminated sites and environmental reservoirs are predicted to become the major source of contemporary problems with POPs after production and use is ended. Weber et al. (2008) documents the experience with POPs contaminated sites, contemporary problems and discuss future relevance and challenges. One of the matters discussed is the mobility of contaminated sediments. The authors conclude that while historical POPs are generally buried in sediments and largely considered not currently bioavailable, several studies have shown that such contaminants can be remobilised during floods and be part of the aquatic and terrestrial ecosystems. Such events have been common in wet tropical countries and are becoming more common in temperate areas of Australia, Europe and the United States (Weber et al. 2008; and references therein). Extreme weather events in many regions are projected to increase in frequency and intensity because of the climate

change (IPCC, 2007a). The El Niño and La Niña weather patterns have been more frequent and intense in the 20th Century (Li et al. 2011), resulting in greater flooding and extreme weather events (IPCC, 2007b).

66. Several reviews of climate change and interactions with hazardous substances in the environment predicts that climate change will alter the migration patterns of contaminated species (e.g., fish and seabirds), and may cause future transport of hazardous substances to previously uncontaminated regions (Schindler et al. 2006; Macdonald et al., 2005; Blais et al., 2007; Krümmel et al. 2003; UNEP/AMAP 2011; and references therein). In the review by Fox et al. (2009) the boundary for colder water/warmer water species has moved north ward for plankton, benthos, fishes and pole ward for some sea mammals during the last 30 years with increasing temperatures in the surface layers of the north-eastern Atlantic. Migration of temperate species of fish and sea mammals to the Arctic has been observed during this period, while many populations of Arctic species have declined (Fox et al. 2009). Migrating birds and fishes have been an important source of contaminants in some regions as shown by several studies (Blais et al. 2005 and 2007; Choy et al. 2010; Foster et al. 2011; Hallanger et al. 2011).

67. But climate change can also indirectly drive an increase in release from primary sources. Some studies show that a spread of biovectors to new regions due to temperature increase and expansion of climate zones could lead to a larger use of pesticides (Miraglia et al. 2009; UNEP/AMAP 2011; and references therein).

(b) Bioavailability

68. Climate change is predicted to influence environmental conditions in ecosystems and alter the exposure and bioavailability of contaminants (Schiedek et al. 2007). Increased bioavailability may lead to higher internal levels in aquatic, semi-aquatic and soil organisms, depending on the impact temperature change has on the bioaccumulation in species.

69. Several reviews have concluded that increased temperatures can result in increased water solubility of chemicals in freshwater thereby increasing the bioavailability of compounds, as well as increasing the uptake rate in organisms (Schiedek et al. 2007; Noyes et al. 2009; UNEP/AMAP 2011; and references therein) Buchwalter et al. (2003) studied the temperature influence on water permeability and uptake of chlorpyrifos in aquatic insects in fresh water ecosystems with different respiratory strategies in the laboratory. They found an increase in uptake rates with increasing temperature in all species studied suggesting an increase in uptake rates with a warmer climate in aquatic insects. Chlorpyrifos is an insecticide frequently found in the Arctic.

70. Several reviews and studies have concluded that changes in the salinity in seawater may alter the solubility of POPs and thereby their bioavailability for organisms (Ramachandran et al. 2006; Tachikawa and Sawamura 1994; UNEP/AMAP 2011; Noyes et al. 2009; Schiedek et al. 2007; and references therien). Organic compounds are generally less soluble and more bioavailable in saltwater than in freshwater due to the “salting out” effect whereby water molecules are strongly bound by salts making them unavailable for dissolution of organic chemicals (Schwarzenbach et al., 2003). Thus, increased contaminant bioavailability is possible in subtropical latitudes experiencing increased salinity, as well as in estuaries and coastal freshwater ecosystems subject to increased saltwater intrusion or droughts (Noyes et al. 2009). Consistent with this hypothesis, increased mortality due to the organophosphate pesticide dimethoate was observed in salt marsh mosquitoes (Aedes taeniorhynchus) and brine shrimp (Artemia sp.) under hyperosmotic conditions (i.e., 3–4 times the isoosmotic salinity) (Song and Brown, 1998). The authors concluded that the increased toxicity might be attributable to increased dimethoate bioavailability and accumulation at the elevated salinity levels compared to the isoosmotic conditions.

71. Bioavailability of POPs in soils (i.e., a higher proportion may be in the dissolved phase in soil-water) may increase with the predicted decline in soil organic carbon content (Bellamy et al., 2005; Jobbagy et al. 2000; UNEP/AMAP 2011; and references therein). Jobbágy and Jackson (2000) found that total content of organic carbon in soil increased with increasing precipitation and clay content and decreased with increasing temperature in soil in their study of impact climate change may have on soil and vegetation using soil records and data bases representing, boreal forest, crops, deserts, sclerophyllous shrubs, temperate deciduous forest, temperate evergreen forest, temperate grassland, tropical deciduous forest, tropical evergreen forest, tropical grassland/savanna and the tundra.

(c) Changes in trophic structure

72. Climate change is predicted to cause alterations in trophic structures, food sources and migratory patterns, (Schiedek et al., 2007; Noyes et al., 2009; UNEP/AMAP 2011; and references therein). Because of biomagnification, this is probably most important for top predators, in which different contaminant levels may either increase or decrease due to alterations in trophic structures (Mc Kinney et al. 2009). If the diet has increased POP concentration, the predators will also show this as the steady state is achieved.

73. In terrestrial ecosystems, bottom-up controlled changes in trophic structure can result from climate change impacts on vegetation biomass and diversity. The decrease in vegetation abundance predicted in some tropical and arid regions due to observed and projected increases in drought and desertification (IPCC 2077 a, b, c) may have consequences for the bioavailability of POPs in soil (UNEP/AMAP 2011; and references therein). The predicted decline in soil organic carbon content, leading to a higher proportion of POPs in the dissolved phase in the soil-water

system may lead to an increase in bioavailability of POPs in terrestrial ecosystems (UNEP/AMAP 2011; Bellamy et al., 2005 ; Nizzetto etal. 2010; Jobbágy and Jackson, 2000).

74. Climate change is predicted to alter the primary production in aquatic food webs and can have consequences for the POP exposure on different trophic levels up the food chain, and across the food web (Borgå et al. 2010; Carrie et al. 2010; UNEP/AMAP 2011; and references therein). Changes in primary production will have a major effect on the production of organisms at higher trophic levels, but the complexity of the trophic systems leading from primary production to higher trophic level organisms (e.g., fish) makes it difficult to establish predictive relationships (Richardson and Schoeman, 2004). Nevertheless, as suggested by Macdonald et al. (2003; 2005; AMAP 2011), it is conceivable that bottom-up changes in trophic structure could result in organisms being pushed higher or lower in their effective trophic levels and result in exposures to POPs being altered by a factor of 5 to 10 in either direction (Armitage et al. 2011).

75. Top-down control in food webs limits the number of species at lower trophic levels through predation. Impacts from climate change have been observed to alter the predator abundance or preference of prey for some species and then lead to important consequences for their prey at lower trophic levels (McKinney et al. 2009; MacDonald et al. 2005; UNEP/AMAP 2011; and references therein).

76. Food web structure can be altered by the switching of prey by predators, to adapt to the decrease in prey populations or to a decrease in the possibility to hunt. In the Arctic, for example, predators at the top of the food web can adapt to habitat changes (e.g., Arctic foxes, grizzly bears and some birds) by switching between terrestrial and aquatic food webs, which could largely alter their exposure to POPs (Macdonald et al., 2005; UNEP/AMAP 2011). A well-known example of top-down controlled change in the Arctic food web that is linked to climate change is the widespread loss of sea ice cover, an important habitat for many Arctic species including polar bears, seals, walrus and Arctic cod (Macdonald et al., 2005; UNEP/AMAP 2011). McKinney et al. 2009 report on recent changes in feeding ecology, between 1991 to 2007 in polar bears from the Western Hudson Bay subpopulation in the Canadian Arctic, that have resulted in increases in tissue levels of several chlorinated and brominated contaminants. In consistence with climate change predictions and due to earlier sea ice break up in the spring the polar bears changed their diet to a higher proportion of open water-associated seal species compared to ice-associated seal species in years of earlier sea ice breakup. The open water-associated seal had higher tissue concentrations of PCB than the ice-associated seal species. The diet changed thus implied an increase in the exposure of the polar bears. The climate induced shift in diet not only changes the exposure of polar bears to POPs (McKinney et al., 2009), but may also have important long-term top-down controlled effects on food web structure.

77. Migration of new species may alter the trophic structure, and positions of the other species (UNEP/AMAP 2011; and references therein). In addition species that migrate to new places due to a changing climate may have higher tissue concentrations of POPs (UNEP/AMAP 2011; and references therein). Field studies in the Arctic have shown that migrating species had higher POP concentrations than Arctic species (Buckman et al. 2004; Hallanger et al. 2011).

(d) Human exposure

Predicting changes in human exposure to contaminants related to climate changes is very difficult. The environmental burden of contaminants may change due to temperature and rainfall changes and increased climate variability (storms, typhoons, hurricanes, etc.). A changing climate may increase the mobilization from environmental reservoirs as described in subsection 4.2.a, and the bioavailablity of the chemical as described in subsection 4.2.b.

The effect on levels in diets and in residential areas will be of relevance, since the most important exposure routes for POPs are through diet, house dust and indoor air. Increased environmental exposure of POPs to food resources, such as crops and domestic animals and remobilization of POPs into water reservoirs may increase the levels in food and water in some regions (Miraglia et al. 2009). In regions where temperature increases and less rainfall is projected, levels of airborne particulates may increase, which could be a particularly problem in urban areas or residential areas that are near contaminated sites and industrial activity (UNEP/AMAP 2011). An increase in bio vectors may increase the use of pesticides and increase the exposure of humans through food and water (Miraglia et al. 2009), as well as through the application of pesticides to crops.

Populations most likely to be affected by the climate induced impacts on POPs are those which are in the poorest health, have less access to health care, are less educated (especially about how to avoid exposures), crowded in dense urban-industrial areas, living in crowded housing and/or are more reliant on subsistence foods (UNEP/AMAP 2011). In areas where POPs increase beyond their current levels, immune-suppression could also increase. For populations already compromised by poor general health and diet, suppression of the immune system could result in more frequent and longer lasting infections, especially for newborns. This is especially significant for regions where temperatures and moisture levels increase as a result of climate change because insect-borne disease vectors and bacteria may both proliferate and spread into these areas.

(e) Summary

78. Table 2 summarizes the key impacts that climate change can have in altering the exposure of POPs relevant for consideration in a review of a substance.

Table 2. Select effects of climate change, their impact on exposure to POPs, and a short description of the impact. (0 = no effect, ↑ increase, ↓ decrease)

Climate change impact	Impact on exposure	Short description of the impact
↑ temperature	↑	Increased temperatures is predicted to lead to increased water solubility of chemicals increasing their bioavailability
↑salinity ↓salinity	↑ ↓	Changes in salinity are predicted to have an effect on bioavailability of organic contaminants
↓↑Primary production	↓↑	Climate change is predicted to alter the primary production in an aquatic food web and give consequences for the POP exposure on different trophic levels up the food chain and across the food web. The complexity of the food chains makes it difficult to establish predictive relationships.
↑POP levels in prey ↓POP levels in prey	↑ ↓	Changes in trophic structure, altered preference of prey and Migration of new species with new contaminants are predicted to alter the levels of POPs in prey and the exposure of predators for POPs.
↑ releases from new and old sources	↑	Remobilisation from environmental reservoirs, landfills and contaminated sites through soil erosion, revolatilization, glacier melting, melting of ice and snow, permafrost thawing, flooding, sea-level rise, increase in frequency of extreme weather events. Larger use of pesticides due to increased occurrence and spread to new areas of vector-borne diseases

4.3. Degradation

(a) Abiotic degradation

79. The increase in temperature induced by the climate change is predicted to increase the abiotic and photolytic degradation of organic substances in soil and sediments (UNEP/AMAP 2011; Noyes et al. 2009; Dalla Valle et al. 2007; Bailey 2003; Elbeit et al. 1983; RIVM 2010; Beach et al. 2006).

80. In air, stronger solar radiation in regions with less cloud cover and rain could lead to higher concentrations of OH radicals in air, which increase the photolytic degradation of substances and their degradation initiated by the hydroxyl radical of airborne chemicals (Mandalakis et al., 2003; UNEP/AMAP, 2011). But particle-bound POPs may be less prone to abiotic and photolytic degradation in the atmosphere due to the strong chemical bonds to airborne particulates (UNEP/AMAP 2011; Scheringer, 1997; Macdonald et al., 2005).

81. For most POPs having a high persistency in the environment, the increased release from primary and secondary sources with increasing temperatures is predicted to be of more importance than an increase in degradation of the compound (UNEP/AMAP 2011). This is especially evident for POPs, such as PFOS, since PFOS according to

Beach et al. (2006) is thermally stable and does not hydrolyze photolysis or biodegrade at any conditions in the environment. In an ecotoxicological evaluation by Beach et al. (2006) hydrolysis and photolysis of PFOS were found to be insignificant, with a hydrolysis half-life of ≥ 41 years at 25 °C and a photolysis half-life of > 3.7 years at 25 °C.

82. In the review by Noyes et al. (2009) enhanced soil moisture in flooded areas or areas with heavy rains is predicted to increase hydrolytic degradation of some substances in soil, but the increase in degradation is assumed not to affect POPs since they are relatively resistant to hydrolysis (Noyes et al. 2009).

(b) Microbial degradation

83. An increase in temperature can affect the microbial systems in sediments and soils with implications for the microbial degradation of POPs (UNEP/AMAP 2011; Noyes et al. 2009; Benimeli et al. 2007). An increase in temperatures may result in increased water solubility of POPs. The effect on microbe populations may be growth and increased metabolic activity, which will likely lead to an increase in microbial degradation of POPs. But increased thermal stress may also hamper the microbial activity and change the composition of the bacterial communities (UNEP/AMAP 2011). On the other hand, microbes are suspected to endure climate fluctuations better than other organisms (Noyes et al. 2009).

84. Climate change interacts with acidification and recovery from acidification in fresh water systems, in particular, in regions affected by historically high acid deposition (Keller et al. 2005; Monteith et al. 2007; Adrian et al. 2009). In remote mountain lakes, temperature effects, rather than acid deposition, appear to dominate changes in lake acidity (Sommaruga_Wörgrath et al. 1997). Climate variations and changes in sulphur and nitrogen deposition from the atmosphere influence the acid–base balance of sensitive lakes in a complex and site-specific way (Curtis et al. 1996; Yan et al. 1996; Wright and Schindler 1995). For example, although lakes in several regions have shown a decline in sulphate concentration following reductions in atmospheric sulphate deposition(Gunn and Keller 1990; Ek et al. 1995; Kros et al. 1995), the expected recovery of pH and alkalinity has not always taken place, implicating an additional response to changes in the local climate. Lakes not sensitive to acidification, with a buffer capacity and solute content (soluble rocks in the catchments), have shown an increase in solute content in (base cations, SO4). This can be due to enhanced weathering rates and increasing solute export from the catchment, both for direct and indirect climate effects (Rogora et al. 2012). Sommaruga-Wörgrath et al. (1997) reported a study of 57 remote alpine lakes which shows that, between 1985 and 1995, lake pH and the concentration of sulphate, base cations and silica have increased, whereas inorganic nitrogen concentrations have decreased. This contrasts with atmospheric input trends, which have led to a decrease in sulphate and a slight increase in nitrogen deposition over the same periodPuxbaurm et al. 1991; Mosello et al. 1985)7,8. The authors of the study propose that the changes in lake chemistry are therefore likely to be caused by enhanced weathering and increased biological activity resulting from an increase in air temperature of about 1 °C since 1985. Their analysis of an alpine lake core covering a 200-year period provides further evidence for a strong positive correlation between pH and mean air temperatures, and thus for the high sensitivity of lakes at high altitudes and high latitudes to climate warming. The acidification of oceans is already described in chapter 4.1 b.

85. Most soils would not be subject to rapid pH changes resulting from climate change (FAO 1993). In most soils, the ongoing decomposition of organic matter maintains CO2 concentrations in the soil air far above atmospheric concentration even now, and CaCO3 solubility is determined by the partial pressure of CO2 in soil air and its activity in soil water, rather than in the atmosphere. Leaching of lime is thus positively related to rate of organic matter decomposition, negatively to gas diffusion rate, and positively to amount of water percolating through the soil. But exceptions might be found in potential acid sulphate soils, extensive in some coastal plains and estuaries, if they become subject to increasingly long dry seasons (FAO, 1993). Buffering in non-calcareous soils is less strong than in calcareous soils, but depends on the cation exchange capacity at soil pH. Even though most of such soils are clays with moderate or high cation exchange capacity, the amounts of acid liberated in such soils upon oxidation generally exceed this rapid buffering capacity. Depending on the efficiency with which the excess acid formed can be leached out, the period of extreme acidity and aluminium toxicity may last between less than a year and several decades. In soils with variable-charge surfaces of the clay fraction, this decreases with acidification. In conditions where leaching is accelerated by climate change, it would be possible to find relatively rapid soil acidification after a long period with little apparent change, as has been the case - but after a shorter latent period - in some soils in Europe that have been subject to acid rain for several decades (FAO, 1993). The soil might in fact be steadily depleted of basic cations, but a pH change may start, or may become more rapid, once certain buffering pools are nearly exhausted. Non-linear and time-delayed effects are expected to occur in various ways at different times after increased temperatures and changed rainfall patterns will have been operative (FAO, 1993).

86. The expected acidification will have importance for the microbial activity, and bioavailability of substances and changes in pH sediments will affect the degradation capacity of the microorganisms (UNEP/AMAP 2011; Sylvia et al. 2005; Elbeit et al. 1983; USEPA 1981; Pardue et al. 1988). The degradation of a substance may then either increase or decrease depending on several factors. While some POPs may remain exceptionally stable at all pH ranges in soil, the degradation of other POPs may increase or decrease due to alterations of the pH. The effect of pH on the degradation of several pesticides in soil leachates were examined by Elbeit et al. (1983). They found that

dieldrin remained exceptionally stable at all pH ranges, while the environmental persistence of endosulfan and γ-HCH progressively increased with decreasing pH.

87. A change to warmer microclimate and acidification caused by climate change processes can also alter the diversity of microorganisms and the species composition present. The impact on the degradation of substances depends then on the capacity of the species that remains or move in from other areas (Noyes et al. 2009; AMAP 2011). The majority of soil microbes thrive in neutral pH (6-7) due to the high availability of most nutrients in this pH range, but there are examples of microbes (especially fungi) that can tolerate pH of 1 to 13 (Sylvia et al. 2005). Alterations in pH can render essential microbe enzymes inactive and/or denature proteins within the cells and prevent microbial activity from occurring (Sylvia et al, 2005; UNEP/AMAP 2011).

88. Increased salinity due to evaporation of seawater because of higher surface air temperatures has an effect on the microbial activity (Noyes et al. 2009; Sogn and Brown 1998; Rajasekhar and Sethunathan 1985). Rajasekhar and Sethunathan (1985) studied the effect of salinity on the environmental persistence of parathion, an organophosphate compound and insecticide. The environmental persistence was significantly higher in flooded saline soil compared to non-saline soil, and increasing with increased salinity. They examined the dehydrogenase activity by microbes and found that the dehydrogenase activity decreased with increased salinity of the soils. In the most saline soil, dehydrogenase activity was almost negligible. The authors highlighted the problem of the increased persistency of pesticides in vast areas under rice cultivation in the tropics and subtropics of salt-affected soils. They concluded that in arid and semi-arid areas of the tropics, long-term environmental persistence of pesticides may be common and serious because of low rainfall, poor leaching and consequent accumulation of salts.

(c) Summary

89. Table 3 summarizes the key impacts that climate change can have in altering the degradation of POPs, relevant for consideration in a review of a substance.

Table 3. Select effects of climate change on degradation of POPs, and a short description of the impact. (0 = no effect, ↑ increase, ↓ decrease)

Climate change impact	Impact on degradation	Short description of the impact
↑ solar irradiation	0 or ↑	Increased photolytic degradation rates is predicted with increasing temperatures in the surrounding media
↑ temperature	0 or ↑ ↓ ↑	Increased abiotic and photolytic degradation rates is predicted with increasing temperatures in the surrounding media Both increased microbial degradation or hampered microbial activity is predicted and depends on the capacity of the microorgansims to endure thermal stress
↓pH	↑↓	Increased microbial degradation or hampered microbial activity is predicted depending on the capacity of the microorganisms to endure climate fluctuations
↑salinity ↓ salinity	↑ ↓	Alterations in salinity is predicted to have effect on the microbial degradation.

4.4. Accumulation in organisms and food webs

90. Climate change is expected to alter the levels and rate of accumulation of contaminants in organisms due to the changes in various environmental and ecological parameters. The magnitude and direction of those changes will differ depending on the extent of temperature increase, organisms and food web characteristics.

91. Increased temperatures can increase the uptake rate of substances across the cell membrane in organisms (Buchwalter et al. 2003; Noyes et al. 2009; Lydy et al. 1999). The effect of increased temperatures on the levels of POPs in organisms depends on the uptake rate and the ability of the organisms to excrete or biotransform the

substance, and differs between species. The result can therefore be both increased and decreased levels and rate of accumulation in organisms.

92. For poikilothermic species[4] (cold-blooded) organisms, such as invertebrates, fish, amphibians and reptiles it has been shown that increased temperatures will enhance the internal uptake in gills and the intestines (Lydy et al., 1999; Buchwalter et al., 2003) but also the biotransformation and elimination rates (Maruya et al., 2005; Buckman et al., 2007; Paterson et al., 2007.)

93. Increased biotransformation and elimination rates due to warmer temperatures are only expected to be of minor importance in modulating exposure and effects for most POPs, which are usually less susceptible to biotransformation and elimination in most species compared to other substances. Where biotransformation does occur, enhanced metabolism could lead to an increased exposure to toxic metabolites due to biotransformation of POPs (Maruya et al., 2005; Buckman et al., 2007; Paterson et al., 2007). If the metabolites are toxic the consequence for the organism depends on its ability to excrete the metabolite or detoxify it. The ability to excrete or detoxify toxic substances depends on type of substances with large variations between species.

94. In a modeling study by Borgå et al. (2010), the changes in various bioaccumulation rates in a marine food web due to increased temperature was only minor, compared to other changes affecting exposure such as bioavailability due to increased primary production (Borgå et al., 2010).

95. The effect on biomagnification depends on the accumulation of the contaminant (rates and levels) at the different trophic levels, the transfer efficiency up the food chain, the composition of the food chain (branched, short or long), and species involved. Climate change is projected to cause alterations in trophic structures, food sources and migratory patterns, which may influence the biomagnification of some POPs (Schiedek et al., 2007; Noyes et al., 2009). This is probably most important for top predators, in which different contaminant levels may either increase or decrease due to alterations in trophic structures changing the transfer efficiency of contaminants up the food chain (Mc Kinney et al. 2009).

(a) Summary

96. Table 4 summarizes the key impacts that climate change can have in altering the accumulation levels and accumulation rate in organisms/food chains of POPs that is relevant for consideration in a review of a substance.

Table 4. Select effects of climate change, their impact on the accumulation levels and rates of POPs in organisms, and a short description of the impact. (0 = no effect, ↑ increase, ↓ decrease)

Climate change impact	Impact on accumulation levels and rate in organisms/food chains	Short description of the impact
↑ temperature	↑	Increase in uptake rates of POPs from the surrounding media in poikilothermic organisms is predicted with increasing temperature.
	↓↑	Depends on the increase in uptake rates versus the magnitude of increase in elimination rates in poikilothermic organisms and their ability to biotransform and excrete POPs.
Changes in food web structure	↓↑	Climate change is predicted to cause alterations in trophic structures, food sources and migratory patterns, which may influence the biomagnification of some POPs

4.5. Environmental transport and distribution

(a) Chemical partitioning

97. Climate change has the potential to affect the transport, behavior and distribution of organic pollutants, between air, water, soil and sediments (UNEP/AMAP 2011). The important chemical properties affecting environmental fate of organic compounds are volatility, phase partitioning, and degradation kinetics, and they are all sensitive to temperature and hydrological change (Mac Donald et al. 2005; Wania 2006). Direct effects of climate

[4] A poikilotherm is an organism whose internal temperature varies considerably. Usually the variation is a consequence of variation in the ambient environmental temperature.

change, such as temperature increase, modification of wind and precipitation patterns, sea level rise, and changes in snow and ice cover, may be very effective in altering the partitioning of chemicals. Other consequences of future climate scenarios may cause a change in degradation rates, soil properties, air-particle partitioning of chemicals in air and water, changes in chemical phase composition (liquid-gas) and uptake - rates in biota (Mac Donald 2005; Wania 2006; UNECE 2010; UNEP/AMAP 2011).

98. Increasing temperatures can alter the distribution and transport of a chemical between the different environmental compartments and the equilibrium between the fractions of the chemical in gas phase, in both dissolved phase and particle-bound chemicals in the different media/compartments. A key factor is the increase in the vapor pressure of POPs with increasing temperature. This affects both partitioning between bulk phases (air vs. surface media such as soil, water and vegetation) and between the gaseous and particle-bound phases in air (Mac Donald 2005; Wania 2006; UNECE 2010; UNEP/AMAP 2011). Increasing temperatures and altered salinity may also alter the distribution of the chemical between biota and its surrounding media and the concentration in biota (UNEP/AMAP 2011; and references therein).

99. POPs loaded in the environmental reservoirs (e.g. surface water, soils, vegetation, permafrost, snow and ice) are predicted to be remobilised under certain climate conditions, which would alter the environmental partitioning of POPs through melting and revolatilization (UNEP/AMAP 2011; and references therein).

100. Declining sea ice may also increase atmospheric loading of POPs such as endosulfan to ice-free ocean waters (AMAP 2003; AMAP 2011; UNEP/AMAP 2011). According to the review done by Weber et al. (2010) the air to water transfer during the ice-free summer months is likely to be the major source of endosulfan for the Arctic Ocean.

(b) Long-range transport (LRT)

101. Several reviews of climate change impacts on the environmental transport and partitioning of POPs conclude that climate change will have implications for the LRT of POPs to the poles (Macdonald et al. 2005; AMAP 2011 and 2012; and references therein). POPs are transported away from source regions with moving air masses and, in the long term, also with ocean currents. Transport by ocean currents is particularly important for relatively water-soluble and less volatile POPs. The effectiveness of airborne transport of POPs is determined by the interplay between: transport (i.e., wind speed and direction); removal from air by degradation, which occurs mainly by reaction with OH radicals; and removal from air by deposition, which includes dry and wet deposition of POPs in the gaseous phase and dry and wet deposition of POPs associated with atmospheric particles (aerosols). (Macdonald et al. 2005; UNECE 2010; AMAP 2011 and 2012; and references therein).

102. Many POPs have partitioning properties that allow for efficient exchange between air and terrestrial or aquatic surfaces, as well as partitioning between gas and particle phases in the atmosphere. The LRT of these chemicals through the atmosphere mainly occur by means of repeated cycles of deposition and re-emission. For less volatile chemicals the ability to undergo LRT in the atmosphere is controlled by the LRT of the atmospheric particles to which they absorb (Wania 2006). The particle-gas partition coefficient varies with temperature and a larger fraction of a compound will be in the gas-phase in air with increasing temperature (Wania and Halsall, 2003). This would enhance the LRT, but could also make the chemical compounds more susceptible to photolytic degradation (MacDonald et al., 2005; and references therein).

103. The fraction in gaseous phase or associated with particles depends on the volatility and octanol-air partitioning coefficient of the chemical, and change with temperature (Wania and Halsall, 2003; Wania 2006). According to the review by MacDonald et al., (2005) several higher molecular weight PBDEs and PCDDs are appreciably associated with particles and may be protected during transport from abiotic and photolytic degradation.

104. A decrease in degradation of POPs in the environment due to climate change may be combined with increased release and spreading of the hazardous substance, and may be connected with an increased transport to remote regions, as found in the review by Dalla Valle et al. (2007). Increasing temperature triggers larger release of POPs from primary and secondary sources making them more bioavailable and increasing the environmental transport near the equator and enhancing the LRT to the poles. Hence, the reasoning is that this mechanism is of greater importance than the effect increasing temperatures has on degradation of POPs (Lamon et al. 2009; Ma et al. 2004a; Noyes et al. 2009; UNEP/AMAP, 2011; Ma et al. 2011).

105. An increase in surface air temperature above land and oceans can cause the rate of volatilization of POPs from open sources to increase (Ma et al. 2004; Ma et al. 2011; Su et al 2007; Lamon et al. 2009; Scheunert 1989; Macdonald et al. 2005; UNEP/AMAP 2011). This factor, concerns primary emissions and may be a dominating effect of climate change on the environmental distribution of POPs. However, climate change is also predicted to affect the re-volatilization from secondary sources, and environmental reservoirs (e.g. surface water, soils, vegetation, permafrost, snow and ice) (Macdonald 2005; NorACIA 2009; UNEP/AMAP 2011; AMAP 2011; Ma et al. 2011; Nizetto et al. 2010).

106. The amount of particulate matter in air, sea- and fresh water systems may also be increased by climate change and affect the mobility of particle-associated POPs. Such changes would increase the fraction of POPs

associated with particulate matter in air (Eckhardt et al. 2007; UNEP/AMAP 2011). But, the atmospheric transport of POPs to remote regions may then be reduced due to temporary or permanent deposition to surfaces. However, more association of POPs with particulate matter may also protect a chemical from photolytic oxidation during transit to remote regions and thus increase the LRT potential of POPs (Scheringer, 1997; Macdonald et al., 2005).

107. Although photolytic reactions do not have strong dependence on temperature they will be affected by cloud cover, which is predicted to increase with global warming in some regions (Macdonald 2005; IPCC, 1995). Increased cloud cover in the Arctic will also result in lower OH radical concentrations and less chemical removed by this and other photolytic pathways (Macdonald 2005; and references therein), and this may again enhance the LRT of the substance.

108. Additionally, modified wind fields and higher wind speeds are expected to promote atmospheric transport of POPs and perhaps airborne particulates. Mid-latitude westerly winds have been strengthened in both hemispheres since the 1960s (IPCC 2007 b). These factors might, therefore, counteract the possibility of increased deposition of airborne particles and associated POPs (UNEP/AMAP 2011). Ma et al. 2004 studied the relationship between climatic patterns and interannual variations of hexachlorocyclohexanes (HCHs) concentrations in the Northern America. They found a significant correlation between the atmospheric concentrations of α- and γ-HCH in the region and the variations in surface air temperatures (SAT) associated with large-scale atmospheric phenomena, such as the North Atlantic Oscillation (NAO). This conclusion is supported by a follow up study (Becker et al.2008). Ma et al. (2004) found this to be most likely a result of volatilization of HCHs from soil in the region, a process that is temperature dependent and, therefore, shows a strong association with SAT. HCHs have been found by the same authors to be readily volatilised from the Canadian prairies during spring time, where large amounts of lindane have been used for seed treatment, and transported north wards by air transport (Ma et al. 2003). Lindane is a commercial mixture of HCH-isomers with γ-HCH in 99 % of purity and smaller amounts of other isomers, among them α-HCH. The authors found a strong positive correlation between increased air concentrations of HCHs in the Canadian Arctic during the positive phase of Pacific North American (PNA) circulation pattern, with an anomalous SAT increase in the prairie region, enhancing the volatilisation of HCH and transport to the Arctic. The authors concluded that high air temperatures enhance the volatilization of HCH from reservoirs in soil accumulated in the past, and that favourable atmospheric transport patterns associated with large-scale climate phenomena could increase the LRT of HCH to the Arctic.

109. Changes in rainfall dynamics due to climate change differ between regions. Holmen (2009) found that increased precipitation and washout of particles from air to water along the transport pathways to the Arctic was changing the transport media for HCB and rate of environmental transport.

110. Migrating birds and fish can be important sources of contaminants in some regions as shown by several authors (Blais et al. 2007; Choy et al. 2010 ; Foster et al. 2011; Hallanger et al. 2011). Food web structure, migratory pathways and species distributions are all subject to climate change and variability (Blais et al. 2007). Increased risk of bio transportation of hazardous substances into new areas is likely to be a consequence of a warmer climate (Blais et al. 2007; Hallanger et al. 2011). Migration of temperate marine species into the Arctic and a decline in the populations of Arctic species has already been observed during the last 30 years (Fox et al. 2009).

(c) Summary

111. Table 5 summarizes the key impacts that climate change can have on LRT of POPs, relevant for consideration in a review of a substance.

Table 5. Select climate change impacts, their impact on LRT of POPs, and a short description of the impact. (0 = no effect, ↑ increase, ↓ decrease)

Climate change impact	Impact on LRT	Short description of the impact
↑ temperature	↑	Surface air temperatures are observed to have increased and are projected to further increase due to climate change. The volatilization of POPs from sources is predicted to increase with increasing surface air temperatures. This is predicted to increase the transport of POPs in the atmosphere. Most POPs have a high affinity for particles and a large fraction can be transported with airborne particles shielded from photolytic degradation.
Strenghtened midlatitude westerly winds in both hemispheres	↑	Are predicted to promote atmospheric transport of POPs and airborne particulates.
Changes in rainfall dynamics	↓↑	The changes in rainfall dynamics differs between regions, but is predicted to alter the transport pathway and affect the rate of environmental transport, and

Climate change impact	Impact on LRT	Short description of the impact
		transport medium depending on region and substance.
Changes in species distribution	↑	Transport of POPs with migrating species into remote regions is observed due to change in climate making the environmental conditions supportable for new species.

4.6. Adverse effects

112. Climate change may result in alterations in a range of abiotic factors, such as environmental temperature, salinity, pH and exposure to ultraviolet (UV)-radiation (UNEP/AMAP 2011), and may modulate physiological processes in animals with consequences for chemical uptake, metabolism and toxicity in the organisms (Heugens et al., 2002; Huovinen et al., 2001; Wrona et al., 2006; Noyes et al., 2009; Kim et al., 2010; Jenssen, 2006).

113. Climate change will alter the salinity, pH, eutrophication levels, and water oxygen levels in marine and aquatic ecosystems while also altering the nutritional status of species and their adaptability (Schiedek et al. 2007; UNEP/AMAP 2011; Noyes et al. 2009; Letcher et al. 2010). Toxico-kinetics of POPs and biotransformation to more toxic metabolites can be altered as a direct result of changes in temperature (Schiedek et al. 2007; UNEP/AMAP 2011; Noyes et al. 2009; Letcher et al. 2010). These changes, either alone or in combination, could enhance the adverse effects of POPs on wildlife, increase disease risks, and increase species vulnerability (Schiedek et al. 2007; UNEP/AMAP 2011; Noyes et al. 2009; Letcher et al. 2010).

(a) Temperature induced changes in toxicokinetics, toxicodynamics, physiological adaptation and biotransformation to more toxic metabolites

114. Increased temperature may impact physiological and metabolic processes alter chemical uptake and susceptibility for hazardous substances in poikilothermic organisms (Satpute et al. 2007; Noyes et al. 2009). Poikilothermic animals are highly affected by ambient temperature and the adverse effects of POPs exposure can either be decreased or increased with increasing temperature (Noyes et al., 2009). This appears to relate to the ability of temperature to modulate the chemical uptake and to temperature-induced shifts in physiological and metabolic processes of the exposed organisms (Heugens et al., 2002; Noyes et al., 2009).

115. POP exposure may interfere with the temperature tolerance of poikilothermic organisms (UNEP/AMAP 2011). Patra et al. (2007) investigated the effects of endosulfan on the upper thermal tolerances of four freshwater fishes, silver perch, rainbow trout, eastern rainbow fish and western carp gudgeon, using the critical thermal maximum (CTMaximum) method and found a significant fall in CTMaximum on exposure to endosulfan. The authors concluded that the exposure of endosulfan, when the organism is near the upper end of its tolerance zone may impose significant additional stress decreasing the ability to withstand additional stress of increasing ambient temperature. The mean CTMaximum for the four species was between 25.9 °C (rainbow trout) – 33. 9 °C (eastern rainbow fish) and exposure to endosulfan resulted in a decrease between 2.8 °C (eastern rainbow fish) - 4.8 °C (rainbow trout). Three of the four fish species tested in the study are native to Australia and live in warm water habitats in the Australian cotton growing areas (Patra et al. 2007). The authors compared to the mean temperatures in Australian cotton growing areas where endosulfan is used can rise to 30 °C during the spraying season, and even 40 °C in some areas. The authors conclude that the observed decrease in CTMaximum values caused by sublethal concentrations of endosulfan may reduce the ability of all four fish species to survive natural temperature fluctuations, and that exposure of wild fish to sublethal concentrations in these areas also may limit their ability to survive in high water temperatures. Moreover, the authors concluded that the reported concentrations up to 4 µg /l of endosulfan from Australian Rivers exceeds the 96-h median lethal concentration values found in the study for silver perch.

116. Water quality and fish size effect on the acute toxicity of endosulfan in juvenile rainbow trout was tested by Capkin et al. (2006). Small, medium and large fish was exposed to endosulfan at a water temperature of 13.1 °C, resulting in mortality among especially the smaller size classes. When the temperature was raised to 16 °C the mortality increased significantly for all size classes. The authors concluded that rainbow trout are more tolerant to endosulfan in cool water temperatures (e.g. less than 14 °C), and that less than 1.3 µg/l concentration of endosulfan can be toxic to small rainbow trout in warm water. The authors compare the result with measured levels in the environment, many of them lying close to 1.3 µg/l. They also compare the results to concentrations during storm events in the past with an endosulfan contaminated run-off (with up to 8.6 µg/l endosulfan). One of the storm events that lead to endosulfan contaminated runoff from cotton fields in to the Big Nance Creek that flows into the Tennessee River in Alabama in USA in August 1986, killed 240000 fish of all locally known species in 26 km of the creek.

117. Increased temperature may increase the rate of biotransformation in poikilotherms to more or less bioactive metabolites (Buckman et al. 2007; Paterson et al. 2007; Maruya et al. 2005). Buckman et al. (2007) found that the biotransformation of polychlorinated biphenyls (PCBs) and bioformation of the more toxic metabolite hydroxylated

PCBs increased with temperature in rainbow trout. PCB half-lives in trout were inversely related to water temperature but biotransformation of PCBs were positively related to water temperature.

118. Since changes in ambient temperature will not alter the body temperature of homeothermic animals, changes in the environmental temperature will probably not directly influence toxicity and toxicokinetics in homeotherms[5]. However, uptake of POPs may change due to altered energetic requirements. Recent studies of eider duck suggest increased remobilization of POPs from the body fats during breeding season in colder environments (Bustnes et al. 2010a).

119. POP exposures may affect homeostatic temperature regulation in humans and other homeotherms, and interfere with physiological adaption to heat or cold stress (Watkinson et al. 2003; UNEP/AMAP 2011). Toxic and endocrine disrupting POPs can interfere with physiological and behavioral processes (Colborn, 1995; Zala and Penn, 2004; Wingfield, 2008) that are important for organisms for acclimation and adaptation to climate change (Jenssen, 2006; Noyes et al., 2009). For instance, toxic chemicals impair the ability of animals to respond to changes in environmental temperature (Heugens et al., 2002; Noyes et al., 2009; Dam et al., 2012). Thus, toxic or endocrine effects may directly affect fecundity and/or survival, which can have a direct consequence on population size.

120. Elevated ocean temperatures and agrochemical pollution individually threaten inshore coral reefs, but these pressures are likely to occur simultaneously in a warmer world and may, as demonstrated recently by van Dam et al. (2012), act together in an additive joint manner to decrease the resilience of symbiotic algae living in the coral reef. More specifically van Dam et al. (2012) demonstrated the additive joint action of elevated temperatures and the photosystem II (PSII) inhibiting herbicide diuron on the photosystem of benthic forminifera hosting symbiotic algae. The additive joint action was found to render both diatoms and dinoflagellates, but not rhodophytes, more sensitive to heat stress thereby increasing the likelihood of photo-damage and bleaching. In line with the impacts predicted by UNEP/AMAP expert group (2011), the findings in this study shows that environmental pollution may affect organisms' ability to cope with climate change impacts and increase the likelihood of adverse effects. The authors highlight improvement in water quality as a way to increase the resilience of symbiotic photorophs to projected increases in ocean temperatures.

121. It may also be of importance to take the transformation products properties into consideration, since they will increase in abundance with increased degradation and can be as toxic as or more toxic than their precursor (Schenker et al. 2007; UNEP/AMAP, 2011). With an increasing temperature the uptake rate will increase in both pokilothermic and homeothermic organisms.

(b) Other effects

122. Climate change has been observed to cause shifts in precipitation and evaporation patterns, terrestrial freshwater run-off and ice melt in many regions and alterations in the salinity in many aquatic areas (IPCC 2007 a, c) (see 4.1 b). Several reviews state that the salinity-contaminant interactions are complex, since salinity can influence the bioavailability of the chemical as well as increase the vulnerability of organisms for contaminants (Schiedek et al. 2007; Noyes et al. 2009; UNEP/AMAP 2011; and references therein). Organic compounds are generally less soluble and more bioavailable in saltwater than in freshwater due to the "salting out" effect whereby water molecules are strongly bound by salts making them unavailable for dissolution of organic chemicals (Schwarzenbach et al. 2003). The increased adverse effects on organisms observed at altered salinity has been attributed to higher physiological costs for organisms to maintain osmoregulation, leading to a decline in fitness and elevated sensitivity to contaminants (Noyes et al., 2009; Schiedek et al. 2007; UNEP/AMAP 2011; and references therein). Several studies have found increased adverse effects due to elevated salinity in the surrounding waters, but also a decline in salinity have been found to be problematic for tidal organisms (Noyes et al. 2009; Hall et al. 1995; Staton et al. 2002). Especially gill-breathing animals (invertebrates and fish), amphibians and marine reptiles and sea birds are likely to be vulnerable to the combined effects of POPs and salinity changes related to climate change (UNEP/AMAP 2011).

123. Biota in some regions is predicted to experience an increase in UV-radiation because of climate change (ACIA 2005; Wrona et al. 2006; UNEP/AMAP 2011; and references therein). Exposure to UV-radiation can cause biomolecular, cellular and physiological alterations in exposed plants and animals (Wrona et al., 2006), resulting in a decline in fitness and an elevated sensitivity to contaminants. In addition, UV radiation can alter the chemical structure of toxicants, rendering them more toxic or less toxic to animals (Noyes et al., 2009; Huovinen et al., 2001; Kim et al. 2010). Synergistic interactions of UV-radiation and contaminants have been suggested to be a factor in population declines of amphibians (Blaustein et al., 2003), and there is evidence that organic compounds may pose a greater risk to aquatic organisms when exposed to ultraviolet light (Schiedek et al. 2007).

124. The current expansion of anoxic and hypoxic areas in aquatic systems due to increased uptake of carbon dioxide in the oceans and fresh water systems is predicted to increase with climate change (Schiedek et al., 2007; Catalan et al. 2009; UNEP/AMAP 2011; and references therein). Hypoxia may alter the toxicity of hazardous

[5] In homeotherm species thermal homeostasis is maintained through different physiological processes and internal temperature is less affected by the ambient environmental temperature.

chemicals through interfering with physiological processes in the organism (Schiedek et al. 2007; Prasch et al., 2004; Fleming and Di Giulio 2011; Fleming 2010). For benthic groups that are favoured by high TOC (total organic carbon) and less sensitive to hypoxia and sulfide (e.g., annelids and echinoderms), the effects of contaminants will be reduced while for arthropods, which are more sensitive to TOC and hypoxia, the effects of contaminants will be increased (Lenihan et al., 2003). Factors such as hypoxia and anoxia may act as co-varying stressors with contaminants, causing damage to organisms that are more dramatic than the effects of any one of these stressors by itself (Shiedek et al. 2007). Hypoxia has been shown to decrease the organism's ability to induce its detoxifying system and may similar to many POPs disrupt the endocrine systems of fish (Schiedek et al. 2007).

125. Fleming and Di Giulio (2011) investigated the role of CYP1A inhibition in the embryotoxic interactions between hypoxia and polycyclic aromatic hydrocarbons (PAHs) and PAH mixtures in zebrafish. PAH are considered a POP in the regional POP protocol under the Convention on Long-range Transboundary Air Pollution, but have not been reviewed under the Stockholm Convention. They found that the toxicity of environmentally relevant PAH mixtures were exacerbated severely by hypoxia to induce or worsen pericardial edema and cause mortality and that a mixture of benzo(a)pyrene and benzo(k)fluoranthene interacted synergistically with hypoxia to induce pericardial edema in developing zebrafish. The authors connected the findings with the environmental conditions in several coastal areas heavily impacted by human activity and PAH contaminations, that experience regularly events of hypoxia, like Cheasepeake Bay, the Gulf of Mexico and the Black Sea. They also related the results with the reports of increasing occurrence and severity of events of hypoxia as a result of human activities in coastal areas and the predictions of further increase due to global climate change by Diaz and Rosenberg (2001) and Schiedek et al. (2007).

(c) Summary

126. Table 6 summarizes the impacts of climate change can have on adverse effects of POPs relevant for consideration in a review of a substance.

Table 6. Select climate change impacts, their impacts on adverse effects of POPs, and a short description of the impact. (0 = no effect, ↑ increase, ↓ decrease)

Climate change impact	Impact on adverse effects	Short description of the impact
↑ temperature induced changes in toxicokinetics, toxicodynamics, physiological adaptation and biotransformation to more toxic metabolites	↓↑	Increased temperature is predicted to impact physiological and metabolic processes, alter chemical uptake and susceptibility for hazardous substances in poikilothermic organisms
	↑	Chemical toxicant exposures is predicted to affect homeostatic temperature regulation in humans and other homeotherms, and interfere with physiological adaption to heat or cold stress
	↓↑	Increased temperature is predicted to increase the rate of biodegradation in the environment and biotransformation in poikilotherms to more or less bioactive metabolites.
↓↑ salinity	↑	Altered salinity is predicted to result in a higher physiological cost for organisms to maintain their osmoregulation and may alter the bioavailability of POPs.
↑ UV-radiation	↑	UV-radiation is predicted to cause biomolecular, cellular and physiological alterations in organisms making them more susceptible to contaminants and alter the toxicity to hazardous substances.
↑Hypoxia	↑	Hypoxia is predicted to alter the toxicity of hazardous chemicals through interfering with physiological processes in the organism.

5. How the POPRC may consider documented climate change impacts on specific new POPs following the rules in the Convention and the scientific approach used by POPRC

5.1. General remarks

127. From the discussion in the preceding chapters, along with the global review of the impacts of climate change on the dynamics and toxicity of persistent organic pollutants (POPs) (UNEP/AMAP, 2011), one can conclude that climate change impacts are likely to affect the environmental fate and transport of POPs, as well as their adverse effects in the environment. Climate change impacts do not change the intrinsic properties of POPs but are relevant when considering their conditional expression in the environment.

128. The findings of observed and predicted climate change impacts and their predicted interactions with POPs will be relevant to consider when presenting information on persistence, bioaccumulation, long-range transport and adverse effects in the screening phase of a candidate POP. This information also applies to the environmental fate and transport and hazard assessment in the development of the risk profile. In the evaluation of new POPs in the screening stage and in the risk profile scientific data with given uncertainties for the specific chemical under evaluation is usually used. However, as the data on the impacts of climate change on chemicals is very limited consideration should be given to data on analogous substances where scientifically supportable (see paragraph 202-204 in chapter 6). In the review process the information and uncertainties in the documented scientific findings will be discussed and handled along with the scientific approach used by the Committee, as described in chapter 6.

129. In the review of new POPs regional differences in climate change as observed and projected by IPCC should be taken into account. The uncertainties in the findings of observed and projected climate change impacts are given in the technical summary of the fourth report by IPCC (IPCC 2007, a).

130. The global review by the UNEP/AMAP expert group (2011) highlights the importance exploring and disseminating information on possible mitigation activities and the co-benefits of managing POPs, other contaminants and climate change in an integrated manner. Along with the recommendations by UNEP/AMAP expert group (2011) it will be important to explore and assess opportunities for co-benefits and mitigation measures to reduce emissions of greenhouse gases and POPs through appropriate life-cycle management options and relevant regulations, when evaluating impacts of mitigation activities for new POPs in Annex F and the development of a risk management evaluation.

131. This chapter provides guidance on how the POPRC may consider documented climate change impacts on specific new POPs in a proposal to the Secretariat for listing a chemical in the Annexes A, B and/or C , the screening phase, the development of a risk profile and the risk management evaluation. The guidance is given in light of the relevant criteria in Annex D, E and F. The chapter also gives practical examples of interactions between climate change and listed POPs from the literature, and how they may be considered.

132. The description of the different stages in evaluating a new substance is based on the "Handbook for effective participation in the work of the POPs Review Committee"[6] and the Convention text.

5.2. Screening assessment under Annex D

133. Any Party may submit a proposal to the Secretariat for listing a chemical in Annex A, B or C in the Convention. The Secretariat verifies that the proposal contains information specified in Annex D and forwards it to the POPRC for consideration.

134. Documentation of the impact climate change may have on a nominated substance should be collected by the nominating Party. If the nominating Party, based on available documentation, finds that the climate change impact may add to the concern that the use and production of the chemical poses for the environment and human health then the Party may highlight this information in their statement of reasons of concern in the proposal to the Secretariat for listing a chemical in the Annexes A, B and/or C , cf. 2 in Annex D in the Convention.

135. Based on the information provided in the proposal submitted by the nominating Party, the Committee shall apply the screening criteria for persistence, bioaccumulation, LRT and adverse effects set out in Annex D of the Convention (see annex I in this guideline) and will on this basis make a decision on whether the chemical fulfils the screening criteria.

136. The evaluation should address all the criteria in Annex D and conclude for each criterion whether it has been fulfilled or not. The draft evaluation contains an overall conclusion on whether the requirements in Annex D have

[6] http://chm.pops.int/Convention/POPs%20Review%20Committee/Publications/tabid/345/Default.aspx

been fulfilled including information according to paragraph 2 of Annex D (statement of reason of concern), where possible. In this process and in line with paragraph 3 of Article 8 of the Convention the screening criteria shall, be applied in a flexible and transparent manner by the POPRC and the Committee in their final conclusion and should consider all the information in an integrated and balanced manner.

137. The criteria in Annex D are constructed to ensure that substances that may be of concern can proceed to the next stage; the development of a risk profile, with a more careful investigation of the global risk the substance may pose. Alternative criterions are listed for persistence, bioaccumulation, long-range transport and adverse effects to capture substances that may be of concern. Also criteria related to the conditional expression of the persistence and bioaccumulation properties of the substance in the environment are listed, to ensure that substances lacking information on the intrinsic properties will proceed and be more carefully evaluated in the next stage. Climate change impacts in a real-life exposure scenario can affect and modulate physicochemical and biological processes, such as the release of contaminants and their degradation in the environment, transport and fate of contaminants in the environment, accumulation of levels of contaminants in organisms, their bioavailability to organisms, and vulnerability of organisms to the contaminants. Thus, climate change may impact the long-range transport and adverse effects in the environment, as well as the conditional expression of physicochemical properties, persistence, bioaccumulation and toxicity of hazardous substances. Information on climate change may therefore add to the reasons of concern, and be stated in a reason of concern according to paragraph 2 in Annex D. In the screening phase the criteria in Annex D can then be used as a guidance tool to evaluate the information on climate change impacts provided in the Statement for reason of concern in the proposal to the Secretariat for listing a chemical in the Annexes A, B and/or C.

(a) Persistence

138. Climate change impacts on the degradation of substances are described in subsection 4.3. The findings on the impacts of climate change on degradation for a nominated substance should be evaluated together with other information relevant for the two criterions 1 b (i) and (ii) for persistence in Annex D of the Convention in an integrated manner. Scientific evidence on change of degradation rates in the environment due to climate change will not change the intrinsic properties of the substance. However, evidence of decreased degradation rates in the environment may be relevant for the statement of reasons of concern.

Increase in environmental half-lives due to changes in climate factors

139. Under the criterion 1 b (i) in Annex D of the Convention half-lives for water, soil and sediment are set based on these criterion findings on increased environmental half-lives because of changes in climate factors, such as temperature, solar irradiance, pH, salinity and microbial activity may be relevant for the statement of concern.

140. Both findings from standardised laboratory tests and results from field studies may be used. The standardised test methods gives empirical estimates of a chemicals biodegradation potential under standardized conditions and are used as a guiding tool to evaluate the persistence of a substance in comparison with the numerical half-lives for persistence 1 b (i) in Annex D of the Convention and to that of already listed POPs. However, a major limitation of standardized laboratory tests is that the standardized conditions employed are not directly relevant to real environmental conditions (Arnot et al. 2005). In the environment the conditions are variable and more complex. The degradation of a substance in the environment will, among other factors change with solar irradiance, temperature, pH, salinity and microbial activity and have different conditional expressions under different climate regimes. Climate differences in different regions may add to and increase the variability and complexity of the environmental system and make it harder to extrapolate from laboratory to studies in the field. But some laboratory studies may have been related to climate change impacts and environmental relevant temperature levels. The climate change induced effect on degradation is related to the environmental conditions in the field and half-lives derived from field studies may also therefore be an important indication of the impact and relevant for the statement of concern, cf. Annex D, 2.

Field studies and monitoring data indicating increase /decrease in degradation rates with climate change

141. Climate change impacts will also be relevant to consider under the criteria in Annex D, 1 b (ii) Evidence that the chemical is otherwise sufficiently persistent to justify its consideration within the scope of this Convention. Field studies or monitoring data indicating a decrease in degradation with changes in temperature, solar irradiance, pH, salinity and microbial activity will be relevant for the statement of concern, cf. Annex D, 2.

(b) Bioaccumulation

142. The climate change induced effect on accumulation of a substance in organisms and food webs is described in section 4.4. The information on climate change impact should be evaluated together with other information relevant for the three criterions 1 c (i) – (iii) for bioaccumulation in Annex D of the Convention in an integrated and balanced manner when considering the relevance for the statement of concern. The preliminary guidance paper on bioaccumulation evaluation (UNEP/POPS/POPRC.3/20/Annex VI) have been consulted for clarification on important evidence of bioaccumulation for the screening stage that may indicate good reason for careful consideration and for the statement of reasons of concern.

Climate change impacts on levels of BCF or BAF in aquatic species

143. Under the criterion 1 c (i) in Annex D of the Convention numerical values are set for BCFs or BAFs in aquatic species. Information that may be relevant for the statement of concern, cf. Annex D, 2 would be on changes in BCF and BAF values with increased temperatures from laboratory studies in aquatic species, if the findings have been related to climate change impacts and environmental relevant temperature levels.

Climate change impacts on levels of BCF or BAF in other species

144. Information on BCF and BAF values from laboratory studies in other species apply to the criterion 1 c (ii) Annex D in the Convention, that asks for other reasons of concern, such as high bio-accumulation in other species. Information on increases in BCF and BAF values from laboratory studies in other species correlated with increased temperatures may therefore be relevant for the statement of concern, cf. Annex D, 2, if the findings have been related to climate change impacts and environmental relevant temperature levels.

Climate change impacts on bioaccumulation or biomagnification from field data

145. On the basis of the criterion 1 c (ii), detections of increasing levels in biota along with increased temperatures in their surrounding environment may indicate good reason for careful consideration and may be relevant for the statement of reason of concern, cf. Annex D, para2,. Measured data in biota provide a clear indicator that the substance is taken up by an organism.

146. Field studies showing a change in trophic structure resulting in a change in biomagnification in top predators can also be relevant.

147. Data from different studies representing different trophic levels from the same area and increased levels in top predators with temperature increase may also indicate good reason for careful consideration.

Climate change impact exacerbating adverse effects

148. The second criterion 1 c (ii) for bioaccumulation in Annex D includes other reasons of concern, such as high toxicity and eco-toxicity. Climate induced impacts that exacerbate the adverse effects of a substance may therefore also be of relevance for the statement of reason of concern. The interlinkages of climate change and the adverse effects of a contaminant are described in subsection 4.6 and 4.1 c in this guideline.

Monitoring data indicating change in detection levels with temperature increase

149. The third criterion, 1 c (iii) in Annex D includes monitoring data in biota indicating a bio-accumulation potential of global concern. On this basis, documentation on monitoring of contaminant levels in food webs in combination with auxiliary information such as temperature, TOC, diet etc over a time period indicating an increase in bioaccumulation or biomagnification may be relevant to highlight in the statement of reason of concern.

Other reasons for concern

150. Detections of increased levels of the chemical under review with climate change in endangered species, in vulnerable populations, human body (blood, milk, fat tissue) and increased exposure due to climate change in the development stage of a species are other reasons of concern that may be relevant to highlight in the statement of reasons of concern based on the criterion 1 c (ii).

(c) Long-range transport (LRT)

151. The interlinkage between climate change and the LRT of POPs is described in subsection 4.5. When considering LRT the Committee shall apply the three criteria in 1 d (i)-(iii) in Annex D in the Convention. When considering the impacts of climate change on physicochemical and biological processes and the implications for the LRT of a compound, relevant information may be monitoring data, the impact of climate change on the conditional expression of environmental fate properties, modelling and the impact on the substance's half-life in air. Considering the impact on the substance's half-life in air in the Convention, both findings from monitoring data and modelling may be used.

152. From the literature it is clear that not only predictions based on modelling will be relevant for the evaluation of climate induced effects on LRT, but also observed changes from monitoring data. The study by Ma et al. (2004) described in subsection 4.5 relies on monitoring data on air concentrations of the contaminant and its environmental fate properties together with data from monitored wind systems in the region and known effects of climate change.

(d) Adverse effects

153. The interactions between the adverse effects of a substance and climate change impacts are described in 4.6 and in 4.1 c. When evaluating the information collected the Committee can apply both the criteria 1 e (i) (evidence of adverse effects) and 1 e (ii) (indication of the potential for damage) in Annex D of the Convention. Most of the climate change induced effects with implications for adverse effects of substances reported in literature are on adverse effects observed in controlled laboratory studies, withrelation to climate change impacts and environmental relevant

temperature levels. In the studies described in 4.6 the parameters used and range of levels are related to natural parameters and their variation in the environment, and are from this aspect of clear relevance for the considerations of adverse effects based on the criterion in 1 (e) (ii) in Annex D and may be relevant for the reason of concern. A large part of the laboratory studies exploring the effects of changes in environmental parameters on the adverse effects of substances in the scientific literature compare the levels used in laboratory to measured levels of the compound in the environment.

154. The environmental parameters investigated in the studies described in 4.6 are related to predicted climate change impacts and most of them may be possible to link directly to effects expected in different regions and may be important to highlight in the Statement of concern from the nominating Party, cf. 2 in Annex D in the Convention.

(e) Examples

Persistence:

155. Rajasekhar and Sethunathan (1985) studied the effect of salinity on the environmental degradation of parathion, an organophosphate compound and insecticide. The environmental degradation was significantly lower in flooded saline soil compared to non-saline soil, and decreased with increasing salinity. The authors highlighted the problem of the increased environmental persistency of pesticides in the vast areas under rice cultivation in the tropics and subtropics of salt-affected soils. They concluded that in arid and semi-arid areas of the tropics, long-term environmental persistence of pesticides may be common and serious because of low rainfall, poor leaching and consequent accumulation of salts. The finding of this type of evidence on environmental persistence may be evaluated according to the criteria in Annex D, 1 b (ii) (evidence that the chemical are otherwise sufficiently persistent).

156. It may be possible to link the finding by Rajasekhar and Sethunathan (1985) to predicted increased temperatures and less rainfall in some regions with arid and semi-arid areas of rice-cultivation of the tropics due to climate change and may then also be important to highlight in the Statement of concern from the nominating Party, cf. 2 in Annex D in the Convention.

Bioaccumulation:

157. McKinney et al. 2009 report on recent changes in feeding ecology, between 1991 to 2007 in polar bears from the Western Hudson Bay subpopulation in the Canadian Arctic, that have resulted in increases in tissue levels of several chlorinated and brominated contaminants. In consistence with climate change predictions and due to earlier sea ice break up in the spring the polar bears changed their diet to a higher proportion of open water-associated seal species compared to ice-associated seal species in years of earlier sea ice breakup. The open water-associated seal had higher tissue concentrations of PCB than the ice-associated seal species. The diet changed thus implied an increase in the exposure of the polar bears. This finding is directly related to the impact of climate change but is also relevant for the criteria 1 c (ii) (high bioaccumulation in other species).

158. The study shows that bioaccumulation of PCB occurs in the marine food web in the Arctic, and the finding is therefore relevant for the criteria 1 c (ii). Secondly the climate change impact can be of concern due to increased exposure and maybe also increased biomagnification.

Long-range transport (LRT):

159. In the thesis of Holmen (2009) the transport pathways, temporal trends and seasonality of POPs was examined, by analyzing the atmospheric POP measurements from the Zeppelin monitoring station in the Norwegian Arctic from 1993 to 2007 and ice core collected nearby. The data were correlated to large scale atmospheric patterns, NAO and Arctic Oscillation (AO), and transport pathways using a transport model to track the origin of the emissions. The author found that strong NAO lead to a slight forcing of γ-HCH in Zeppelin air, although from the ongoing use and production of lindane in the United States and Canada a greater forcing on γ-HCH concentrations at Zeppelin was expected. Lindane is a commercial mixture of HCH-isomers with γ-HCH in 99 % of purity and smaller amounts of other isomers. The author concluded that γ-HCH most likely was washed out before entering the Arctic, based on the quite low Henry Law Constant (HLC) of γ-HCH, which implies high tendency to partition into water. The pathway that North American air follows on its way to the Arctic was found to be of importance as well. During the transport of the North American air across the Atlantic Ocean relatively cold air masses meet the warm ocean, and cold condensation and wet scavenging of pollutants occur.

160. The author found further that for compounds like the HCHs, which are semi-volatile, have a low HLC and partition strongly into cold water, a change in transport medium from the atmosphere to the ocean may occur due to the climate change. Since the rate of precipitation is expected to increase with a warmer climate in the Arctic and the neighbouring regions, more washouts of pollutants from the atmosphere by rain can then change the transport mode from atmospheric transport to transport by ocean currents. This would make the transport from North America to the Arctic considerably slower. In the Arctic the γ-HCH will evaporate from the ocean back to the atmosphere due to higher surface air temperatures and volatilization rates as a consequence of the climate change. The author concluded based on this that even if the production of γ-HCH were to stop completely; γ-HCH will still be detected at Arctic

measuring stations for many years ahead due to the build-up in the ocean transport pathways. The findings are based on monitoring of γ-HCH in the Arctic air, environmental fate properties for γ-HCH, and transport model to track the origin of the emissions. It is further correlated to climate change impact on removal processes in air and transport pathways in the Arctic. The POP criteria of relevance for the consideration of LRT using this type of evidence would be 1 (d) (ii) in Annex D (monitoring data) and may be discussed in relation to the criterion 1 (d) (iii) and the half-life in air (2-3 days) for lindane (UNEP/POPS/POPRC.2/17/Add.4). Since this finding underlines the importance of consideration of the half-life in water (3-300 days; UNEP/POPS/POPRC.2/17/Add.4) when considering the LRT potential of lindane.

161. The thesis also shows that this pathway will be even more important in the future due to the climate change for this compound, a consideration that may be highlighted in the document.

Adverse effects:

162. Fleming and Di Giulio (2011) investigated the role of CYP1A inhibition in the embryotoxic interactions between hypoxia and polycyclic aromatic hydrocarbons (PAHs) and PAH mixtures in zebrafish. They found that the adverse effects of environmentally relevant PAH mixtures were exacerbated severely by hypoxia to induce or worsen pericardial edema and cause mortality. They also found that a mixture of benzo(a)pyrene and benzo(k)fluoranthene interacted synergistically with hypoxia to induce pericardial edema in developing zebrafish. The authors connected the findings with the environmental conditions in several coastal areas heavily impacted by human activity and PAH contaminations, that experience regularly events of hypoxia, like Chesapeake Bay, the Gulf of Mexico and the Black Sea. They also related the results with the reports of increasing occurrence and severity of events of hypoxia as a result of human activities in coastal areas and the predictions of further increase due to global climate change by Diaz and Rosenberg (2001) and Schiedek et al. (2007). This finding applies to the criterion 1 e (ii) in Annex D in the convention and is important to include when considering "the potential for damage to the environment". The effect of possible further climate induced increase of hypoxia frequency in some coastal waters that is contaminated by PAH may be important to highlight in the Statement of concern from the nominating Party, cf. 2 in Annex D in the Convention.

5.3. Development of a risk profile under Annex E

163. If the POPRC is satisfied that the screening criteria have been fulfilled, it invites Parties and observers to submit information specified in Annex E and develop a risk profile.

164. In this stage the Committee shall further elaborate on, and evaluate, the information referred to in Annex D, and include as far as possible, any additional information following the criteria in Annex E. A risk profile shall be developed that further elaborates on, and evaluates, the information referred to in Annex D and includes, as far as possible, the information listed in Annex E. An ad hoc working group is set up chaired by a member of the Committee in addition to a drafter. Documentation of interactions between a nominated substance and climate change can be collected and submitted by all Parties and observers to the Committee for consideration by the drafter and the working group. The drafter may also collect additional information from other sources in the preparation. The draft document will be circulated for technical comments from the working group, Parties and observers. In completing the risk profile the comments will be taken into account.

165. Based on the risk profile, the POPRC makes a decision on whether the chemical is likely, as a result of its long-range environmental transport, to lead to significant adverse human health and/or environmental effects such that global action is warranted. When weighing and analyzing the information provided the weight of evidence approach can be used as described in 6.3 b. Lack of full scientific certainty in the risk profile shall not prevent the proposal from proceeding to the next stage of chemical review.

166. Climate change impacts in a real-life exposure scenario can affect and modulate physicochemical and biological processes and thereby impact the conditional expression of parameters that are relevant for the evaluation of hazard assessment of the substance (1 b in Annex E in the Convention) and its environmental fate (1 c in Annex E in the Convention). In addition to scientific peer-reviewed data on the interactions between climate change impacts and the specific chemical under evaluation the following information may be relevant (cf. 1 a, d, e in Annex E); climate change impacts on releases from sources and exposure in local areas; available monitoring data including climate change impacts on levels; and national and international risk evaluations and risk assessments taking into account the climate change impacts.

(a) Hazard assessment

167. According to the risk profile outline the hazard assessment for the endpoints of concern shall further elaborate on the information referred to in Annex D, paragraph (e) (Adverse effects) based on all relevant available information, monitoring data on effects included. The hazard assessment shall include consideration of toxicological interactions involving multiple chemicals according to 1 (b) Annex E in the Convention.

Relevant information on interlinkage between the chemical and climate change for consideration in the hazard assessment for endpoints of concern should be documented scientific data derived from field studies, monitoring and laboratory studies on:

- ❖ The impacts of climate change on exposure, including all the effects and considerations described in subsection 4.2 (b)-(e),
- ❖ The impacts of climate change on and interaction with adverse effects, including all the interactions and effects described in subsection 4.6,
- ❖ The effects of multiple stressors (figure. 2), including exposure to POPs and climate change, on vulnerable species and populations, including all considerations as described in subsection 4.1 (c).

See also the description and considerations for the screening process of bioaccumulation (subsection 5.1 b) and adverse effects (subsection 5.1 d).

(b) Environmental fate

168. According to the risk profile outline further elaboration of information referred to in Annex D, paragraphs (b)-(d), based on all relevant and available information, including monitoring data and data on detected levels when ascertaining the environmental fate of the chemical. The analysis shall include the following as described in 1 (e) in Annex E:

- ✓ The chemical and physical properties of the nominated chemical;
- ✓ The persistence of the nominated chemical;
- ✓ How persistence, chemical and physical properties are linked to environmental transport, transfer within and between environmental compartments, degradation and transformation of the nominated chemical to other chemicals.
- ✓ The bio-concentration factor or bioaccumulation factor, based on measured values, except when monitoring data are judged to meet this need.

Relevant information on the interlinkages between the chemical and climate change when analysing data to ascertaining the environmental fate of the chemical should be documented scientific data derived from field studies, modelling, laboratory studies and monitoring on:

- ❖ Differences in the impacts of climate change in different regions and ecosystems, as well as impacts on environmental partitioning, including all the effects and considerations as described in subsection 4.1 (a)-(b).
- ❖ Climate change impacts on environmental reservoirs, contaminated sites and landfills, as well as spreading of biovectors, as described in subsection 4.2 a.
- ❖ Climate change impacts on degradation, including all the effects and considerations as described in subsection 4.3.
- ❖ Climate change impacts on uptake rates, rates of biotransformation and excretion, bioaccumulation and biomagnification, including all the effects and considerations as described in subsection 4.4.
- ❖ Climate change impacts on the environmental transport of POPs, including all the effects and considerations as described in subsection 4.5.

See also the description and considerations for the screening process of persistence (subsection 5.1 a) bioaccumulation (subsection 5.1 b) and long-range transport (subsection 5.1 c).

(c) The other information requirements listed under Annex E

For the other information requirements listed under Annex E the climate change impact on POPs will be relevant when considering:

- ❖ Releases from sources (cf. subsection 4.2 a)
- ❖ Exposure in local areas
- ❖ Available monitoring data and
- ❖ National and international risk evaluations and risk assessments.

169. Several reports on climate change impact and interaction on POPs and other contaminants are available under the Arctic Monitoring and Assessment Program (AMAP) (www.amap.no) and Arctic Climate Impact Assessment (http://www.acia.uaf.edu/) a joint project between the Arctic Council and the International Arctic Science Committee (IASC).

(d) The synthesis

170. According to the outline for the risk profile (UNEP/POPRC.1/10/Annex IV) a synthesis shall be provided, in the form of a risk characterization, with emphasis on information that leads to the conclusive statement. The synthesis is described as a comprehensive summary rationale, which draws on the critical data elements contained within the body of the report linking them into an overall weight of evidence in "Handbook for effective participation in the work of the POPs Review Committee"[7].

If POPRC finds that the climate change impact on the substance adds to the concern that the use and production of the chemical poses for the environment and human health and is a critical data element for the consideration of need of global control, the Committee may highlight this information in the synthesis.

(e) Examples

Hazard Assessment:

171. Patra et al. (2007) and Capkin et al (2006) found that the survival of rainbow trout depended on the water temperatures when exposed to endosulfan. Capkin et al. (2006) found a 50 % mortality at 19.78 µg/l for rainbow trout at 12,1 °C in a 96 h acute toxicity. When the water temperature was increased to 16 °C °C, no small or medium sized fish survived, while large fish survivors decreased to 77.5 %. Patra et al. (2007) found 50 % mortality at a 1.3 µg/l dose of endosulfan for rainbow trout and three other fish species in a 96 h acute toxicity test performed at 20 °C. They investigated the effects of endosulfan on the upper thermal tolerances of rainbow trout and the other fishes, using the critical thermal maximum (CTMaximum) method. An important finding in the study was that the exposure of endosulfan may impose significant additional stress decreasing the ability to withstand additional stress of increasing ambient temperature, when the organism is near the upper end of its tolerance zone. This agree well with the finding by Capkin et al (2006); that the rainbow trout were more tolerant to cold waters and that less than 1.3 µg/l concentration of endosulfan can be toxic to small juvenile rainbow trout in warm water.

172. In the studies performed by Patra et al. (2007) and Capkin et al. (2006) and as described in 5.2.4 the parameters and the range of levels used are related to natural parameters and their variation in the environment. They are both from this perspective of direct relevance for the considerations of adverse effects and important to include in a hazard assessment.

173. It may also be possible to link the findings in both studies to predicted climate change impacts of increased temperatures in many areas with frequent use of endosulfan in vicinity to rainbow trout waters. The climate change impact may, if relevant to a nominated substance, add to the concern that use and production of the chemical poses for the environment and be highlighted in the synthesis. The synthesis contains information relevant to the risk profile, in the form of a risk characterization, with emphasis on information that leads to the conclusive statement.

Environmental fate:

174. Ma et al. (2010) used a modified perturbed air-surface coupled model to simulate and predict perturbations of POP concentrations in various environmental media under given climate change scenarios. According to the outcome

[7] http://chm.pops.int/Convention/POPs%20Review%20Committee/Publications/tabid/345/Default.aspx

of the simulation, hexachlorobenzene (HCB) exhibits strong response to specific climate change scenarios as shown by its high concentrations perturbations in air. HCB exhibited a positive perturbation in the atmosphere throughout the 30 year period used in the model, reaching maximum at about 2 years and subsequently a steady state after 15 years model integration. The opposite result in water suggests a loss of the chemical due to volatilization. The study is relevant for the environmental fate discussion, as it predicts the future trend caused by the climate change, deduced from more detailed information on environmental fate properties together with the climate change impact on the parameters governing the transport and distribution of HCB. This finding indicates that the impact from climate change will be a large increase in air concentrations of HCB and subsequently decrease in soil and water concentrations as a result of revolatilisation from environmental reservoirs.

175. A strong perturbation occurs for HCB due to its volatilization to air in a closed soil-air system, reaching a steady state after 15 years. The response is found by the authors to correspond to natural conditions, with dramatic increase in air concentrations of HCB under strong El Niño events in the Great Lake region in Canada, a projected outcome resulting from climate change. Adding mean degradation rates for soil and air to the model resulted in a different pattern, with a maximum increase in a single year. After several years of an increase the perturbated atmospheric concentrations tended to decrease due to degradation. An opposite trend was also detected for soil in this system for the first years, and thereafter the concentrations were diminished due to degradation. The increase in air concentrations implies an increased LRT of HCB.

176. The findings by Ma et al (2010) using modelling also coincides with the findings by Bustnes et al. (2010b). Bustnes et al (2010b) assessed the impact of climate variability on temporal trends (1997-2006) of HCB in glaucous gulls breeding in the Norwegian Arctic by Bustnes et al (2010b). The Arctic Oscillation with different time lags was used as a climate proxy. Multiple regression analyses were used to analyse the correlation of HCB concentrations with climate variations, controlling for potential confounding variables (year, sex and body condition). From the results the authors could conclude that gulls had higher HCB concentrations in breeding seasons following years with high air mass transport toward the Arctic, the winter transport being more important than the transport during summer. This corresponded well with that 80% of the annual south- to-north air mass transport occurs in the winter, even if the higher temperatures during summer would increase the volatilisation of HCB from land and water masses. Hence, more northwards air transport during milder years seems to have increased background levels of HCB in the Arctic, which again resulted in higher HCB loadings accumulating in glaucous gulls at the top of the food chain the following breeding season. The study by Bustnes et al. (2010b) will be relevant for the discussion of the environmental fate of HCB related to wind systems, chemical and physical properties and bioavailability. The findings of HCB in glaucous gulls in the Norwegian Arctic in the study by Bustnes et al. (2010b) are important for the conclusion regarding LRT and bioaccumulation of HCB in the Arctic food chain. It illustrates the link between environmental transport in air, deposition and uptake in the Arctic food webs. Climate change impacts are also relevant when discussing the findings of Bustnes et al. (2010b), since the (Arctic Oscillation (AO) is predicted to be stronger with milder winters further south, as a consequence of climate change (Macdonald et al. 2005; IPCC 2007 a).

177. The findings by Ma et al. (2010) and Bustnes et al (2010b) may be an important contribution to the synthesis of information in the risk profile. The synthesis contains information relevant to the risk profile, in the form of a risk characterization, with emphasis on information that leads to the conclusive statement.

5.4. Risk management evaluation under Annex F

178. When the Committee has decided to adopt the risk profile and have reached an agreement on that the chemical "is likely as a result of its long-range environmental transport to lead to significant adverse human health and/or environmental effects such that global action is warranted", the proposal shall proceed to the next stage, the risk management evaluation. In this stage the Committee will prepare a risk management evaluation that includes an analysis of possible control measures for the chemical in accordance with Annex F in the Convention. To be able to conduct its task the Committee invites Parties and Observers to submit information on socio-economic considerations associated with possible control measures, including the considerations on the indicative list in Annex F.

179. According to the “Handbook for effective participation in the work of the POPs Review Committee”[8] the Committee shall identify to the greatest extent possible the social, economic and other consequences of listing the substance. When considering possible options to eliminate or reduce releases of the chemical it may therefore be important to evaluate the measures in the light of the effect on the emissions of greenhouse gasses.

180. An ad hoc working group is set up chaired by a member of the Committee in addition to a drafter. Documentation on possible control measures and their implications for reduction of greenhouse gasses can be collected and submitted by all Parties and observers to the Committee for consideration by the drafter and the working group. The drafter may also collect additional information from other sources in the preparation. The draft document

[8] http://chm.pops.int/Convention/POPs%20Review%20Committee/Publications/tabid/345/Default.aspx

will be circulated for technical comments from the working group, Parties and observers. In completing the risk management evaluation the comments will be taken into account.

181. Based on the risk management evaluation, the POPRC decides whether to recommend the substance to be considered by the Conference of the Parties for listing in Annexes A, B and/or C in the Convention. In doing, so the Committee may include important information on mitigation measures to reduce emissions of Greenhouse gasses and POPs through appropriate life-cycle management options and relevant regulations.

(a) Positive and/or negative impacts on society

182. According to the report “Climate change and POPs: Predicting the impact” it is important that decision makers explore and disseminate information on possible mitigation activities and the co-benefits of managing POPs, other contaminants and climate change in an integrated manner. (UNEP/AMAP 2011). This relates specifically to the consideration of positive and/or negative impacts on society of implementing possible control measures in Annex F (c). For example, it might be appropriate to discuss climate change impacts when discussing alternatives and/or waste and disposal implications depending on the particular chemical being reviewed.

183. For example, according to Annex F an analysis of the agreement between the possible control measures and a movement towards sustainable development should be conducted when considering the positive and/or negative impacts on society (cf 1. c (v) under Annex F).

Relevant information when considering the positive and/or negative impacts on society of implementing identified possible control measures:

- ❖ Impacts on emissions of greenhouse gasses
- ❖ Impacts on energy consumption
- ❖ Co-benefits for the elimination or reduction of the releases of greenhouse gasses and the chemical.
- ❖ Regional risk and national reduction measures taken aiming on reduction or elimination of both greenhouse gasses and hazardous contaminant under evaluation.
- ❖ Existing assessment of co-benefits of mitigation activities including reduction of greenhouse gasses and releases of POPs

184. The following report has been identified in the process with developing this guidance:

- Assessment of co-benefits and trade-off situations between energy conservation and unintentionally production of POPs (Bohmer et al. 2009)

(b) Synthesis

185. According to the outline of the risk management evaluation, the evaluation shall include a synthesis of information relevant to the risk management evaluation, in the form of a risk management strategy, with emphasis on an analysis of possible control measures for the chemical that leads to the concluding statement. This synthesis will include the integration of information on hazard identification, risk assessment, risk control measures evaluation, including a decision-making proposal on control measures, and recommendations for strategy implementation, supervision and review. The analysis of possible control measures should evaluate the full range of potential control measures and conclude, where possible, whether the recommended strategy/strategies are cost-effective, market-neutral and provide benefits to human health and the environment.

If POPRC finds that the analysis of the consequences of possible control measures for energy use or greenhouse emissions will be of relevance for the risk management strategy this may be highlighted in the synthesis.

(c) Example

186. The following conclusions were drawn by the authors of UNEP/AMAP (2011) report on the basis of a comprehensive assessment of co-benefits and trade-off situations between energy conservation and releases of unintentionally produced POPs by the Scientific and technical advisory panel of the Global environmental facility (GEF) (STAP 2009). The conclusions drawn would have been an important contribution to the risk management evaluation of a nominated unintentionally produced POP and applies to criterion 1. c (v) under Annex E, positive and/or negative impact on society and movement towards a sustainable development. If agreed in POPRC it could also have been relevant to highlight in the Synthesis of the Global evaluation management report.

187. There are various technological measures presented within BAT and BEP lists which are directed towards improvement of combustion conditions, energy efficiency, energy recovery rates, and emission reductions (EEA, 2006; Nemet et al., 2010). These measures are designed for application in various industrial sectors and the transportation sector where both GHGs and unintentionally produced POPs can be released to the atmosphere. The following sectors are of particular importance in this context: combustion of fuels in utility burners for electricity and heat production, industrial and residential boilers (particularly those fuelled with wood and other biomass), waste incinerators, crematories, cement kilns, primary and secondary non-ferrous metal industries, pulp production, specific chemical production and motor fuel firing. The choice of specific technology would have a direct impact on releases of GHGs and unintentionally produced POPs.

188. Implementation of various environmental regulations also provides an opportunity to reduce GHGs and unintentionally produced POPs. This issue is of particular importance for waste disposal, which is a very important source of emissions of PCDDs and PCDFs. Open burning and accidental burning of wastes is an important source of GHG emissions on a global scale and one of the largest global sources of POPs. Prohibition of open burning of wastes through adequate domestic and regional regulations could result in significant reductions in emissions of GHGs and unintentionally produced POPs from this source.

189. The effects of climate policies on unintentionally produced POPs and other air pollutant emissions mainly take place in a limited number of sectors: industrial, residential, and transportation. Climate policies are expected to have a positive effect on regional and local scale air pollution by reducing the creation and emissions of unintentionally produced POPs. Table 7 provides a qualitative assessment of unintentionally produced POPs co-benefits during the reduction of CO_2 emissions.

Table 7. A qualitative assessment of CO_2 emission reduction benefits for reduction options and co-benefits for unintentionally produced POPs reduction (STAP 2009; UNEP/AMAP 2011). More information about the assessment will be found in the report "Benefits and Trade-Offs Between Energy Conservation and Releases of Unintentionally Produced Persistent Organic Pollutants, Technical report" (STAP 2009)[9].

CO_2 reduction option		CO_2 benefits	Co-benefits for unintentionally produced POPs reduction
1	Reduction from coal usage	Medium → Large	Medium
2	Reduction from industrial processes	Medium → Large	Medium → Large
3	Reduction from waste incineration	Small → Large	Large
4	Reduction from transportation	Small → Large	Medium → Large

190. Current literature indicates that air quality policies based on structural changes, such as the improvement of energy efficiency in power stations, replacement of fossil fuels by renewable sources, and improvement of combustion processes in stationary and mobile sources, and industrial technologies, can provide greater climate and air pollution co-benefits than the traditional end-of-pipe technologies.

191. Mitigation through implementation of environmental regulations to arrest open burning of waste will also result in co-benefits of reducing GHGs and unintentionally produced POPs.

[9] **The Technical Report was commissioned by the Scientific and Technical Advisory Panel (STAP) and the Technical Annex to STAP's Conclusions and Recommendations to the Global Environment Facility.**

6. Information collection and analysis in the scientific approach used by POPRC

6.1. Methods of data collection

192. The "Handbook for effective participation in the work of the POPs Review Committee"[10] describes the methodology of data collection and information sources for the three different review processes. In addition to collecting information from Parties and observers using formats developed by the POPRC a desk top study is recommended. Searching for relevant data in public and private data bases, gathering published literature from scientific journals, technical reports or notes, commissioned research reports, development assistance study reports as well as internet search is proposed. Contact with relevant stakeholders can also be a useful resource. Relevant stakeholders in the light of this guidance would be organizations assessing the impacts of climate change on POPs and regional and national authorities' that may provide assessments and risk management analysis incorporating the implications of climate change and contaminants.

193. In the report from UNEP/AMAP (2011) a list of International initiatives on chemicals research and assessment is provided in appendix 1, which may provide relevant data.

6.2. Relevant information

(a) Relevant sources of information

194. Relevant information sources will be:

- Peer reviewed scientific data, (eg. laboratory studies, field studies, reviews, modeling and monitoring reports)
- Grey literature, (e.g. government information, agency reports etc.)

195. In Table 3 and 4 in the handbook a non-exhaustive list of public and private databases and other sources of information is provided. The relevant information to be evaluated in the different review stages of a new POP are given in Chapter 5 (screening stage (5.1), risk profile (5.2) and risk management evaluation (5.3).

6.3. Evaluation of data

(a) The scientific approach used by POPRC

196. The review process undertaken by POPRC as described in the "Handbook for effective participation in the work of the POPs Review Committee"[11] is a systematical narrative review (cf. description in Weed 2005) using defined criteria (Annex D. E and F), a clear procedure (Article 8) and clear principles in the review of chemicals (Article 8). It is science based and transparent, seeking consensus between the Committee members, with representation from all geographical regions and different disciplines in natural science. The purpose is to describe the state of the art science and on basis of that on identify potential risk and make recommendations on risk reduction measures using the precautionary approach (cf. preamble to the Convention).

197. A key step in any systematic narrative review is to determine which studies will be included in the application of the interpretative methods used and which will be excluded (Weed 2005). The same is the case for the review of chemicals undertaken by POPRC. All evidence is used, but some evidence is given more weight in the overall conclusion. The decision of which data is given more weight is founded on a scientific evaluation of the data at hand. The evidence is also weighed according to their relevance for the evaluation of the chemical properties and conditional expression against the defined criteria in the annexes, such as POP characteristics, environmental fate and hazard assessment. To get a balanced and nuanced review of the chemical the Committee endeavour to get information from all regions and relevant stakeholders. Priority is generally given to get the most recent data.

198. In the three stages of the chemical review process the information received is discussed and weighted against each other in several steps using a qualitative weight of evidence approach. According to the handbook[5] peer reviewed scientific data should take precedence, while secondary data (e.g. peer reviewed monograph of chemical substance or reviews and tertiary and incidental or anecdotal data) should only be incorporated with great care and with proper caveats. Exclusions of information by the POPRC have been based on concerns about quality, relevance, or reliability. The reason behind differential views in the Committee on the evidence reviewed and decisions on setting chemicals aside are captured in the meeting reports.

[10] http://chm.pops.int/Convention/POPs%20Review%20Committee/Publications/tabid/345/Default.aspx

[11] http://chm.pops.int/Convention/POPs%20Review%20Committee/Publications/tabid/345/Default.aspx

(b) Qualitative and quantitative uncertainty

199. The uncertainties and ranges of climate change impacts will be different for every substance, impact, scientific test/observation and region. Quantifications of the various possible effects and uncertainties in the scientific findings should be evaluated chemical by chemical and based on the documented scientific findings presented. The evaluation of uncertainties or ranges of change related to climate change impact will not be different from evaluation of uncertainties and ranges in other data presented to POPRC. The uncertainties or ranges in climate change related parameters given in the scientific data can be included in the evaluation, in a weight-of-evidence approach, as has currently been the practice of POPRC in the past.

200. When assessing complex environmental problems this may be done quantitatively or qualitatively. A combination of both approaches may also be used. Both quantitative and qualitative approaches have their constraints, which results in different types of uncertainties. This may be reflected in how well the results/ conclusions they produce fit with data measured in the field, how well suited they are to predict and assess certain outcomes such as ecological risks and how reliable they are as tools for policy making.

201. A qualitative approach entails a qualitative weighting of data to make recommendations. The conclusions are drawn from current state of knowledge at a given point in time. The main uncertainty of this approach is that it may be subjective as it relies on the reviewers' scientific knowledge and capability to draw conclusions.

202. A quantitative approach to assessing chemical properties and making recommendations on the other hand relies on consumptions and estimations using numerical criteria with more or less well defined uncertainties. Although quantitative approaches allows for statistical testing, the range of parameters used in the approach may still be subjective in terms of the endpoints and parameters analyzed. The approach can also be incomplete due to the constraint of knowledge or limitations of the study, and the output may therefore be misleading.

203. A combination of the two approaches is recommended in the literature (Coyle 2000, Weed 2005, Sluijs et al. 2005). The weight of evidence approach under the POPRC is combining quantified criteria with qualitative methods in weighing evidence in the chemical review processes.

204. In ecotoxicological science such as other natural sciences most of the evidence is gathered using quantitative or semi-quantitative methods e.g. levels of chemicals in different environmental matrixes are quantitatively measured by suitable analytical methods and compared statistically. The conclusions reported in peer-reviewed publications are however generally drawn is based on a qualitative interpretation of the results and are drawn using findings from other peer-reviewed scientific in a weight-of evidence based approach.

205. The following criteria are usually used when evaluating different types of data;

Modelling: Caution should be exercised when using environmental models, and the reliability and uncertainty of the data generated by such models should always be stated, considered and taken into account. Questions that should be addressed in this regard are: Are the assumptions, model structure and parameters included scientifically valid? Are they incomplete or do they have large uncertainties? Are the levels used relevant to levels found in the environment? Has the model been tested and compared with findings in field studies? Normally more weight would be given to measured data than data generated by environmental models.

Laboratory studies: Laboratory studies never truly mirror the real-life exposure experienced by live wild animals or humans over their life-time and are often conducted at temperatures (and other environmental conditions) and with species that are not directly environmentally relevant. The outcome of a laboratory study is also sensitive to the chosen experimental design and what quality controls were implemented in the study. Questions that may be addressed in this regard are: Are standardized test methods used? Are the tested species including age and sex, temperature and other experimental parameters environmentally relevant, and if not how may the associated uncertainty be taken into account? How can the impacts including additive /synergistic impacts of real world exposure be incorporated into the method? Are the levels used relevant to levels found in the environment? How many animals were analyzed in the study and what is the statistical power of the data? How large are the uncertainties in the statistical methods used? Will the result be representative according to number of animals used in the study; is the conclusion drawn stretching the evidence?

Field studies: Though field studies much like laboratory studies only represent a snapshot in time, field studies are truly representative of what happens in the environment. However, field samples may be hard to obtain and may be collected less frequently. Samples collected in field studies may also be more heterogeneous in nature (e.g., wild organisms may be more genetically diverse than laboratory animals). The number of samples collected and sampling frequency may influence predictive power (e.g. infrequent sampling) of the study/ data and statistical power (e.g. few samples are collected). A large genetic diversity may make it even harder to detect significant differences if sample numbers and frequency is low. The results from field studies may be influenced by other parameters such as seasonal changes/ fluctuations in temperature and weather, as well as the reproductive and nutritional status of the animal tested. Such factors need to be considered when employing the data. Questions to be asked are; Are the results in line with or contradictory to other field studies? Are the results in line with or contradictory with reported laboratory studies? Will the result be representative according to number of animals used in the study? Is the conclusion drawn stretching the evidence? Are the results relevant to other regions and times with different environmental conditions? If not, how might they differ? What is the heterogeneity of the samples tested and how is this considered in the study, is it relevant? Does the study take into account multiple stressors and seasonal changes in temperature and weather?

Risk assessments: POPRC often employ data from national or regional risk assessments. When such data are considered relevant questions to address may be: how large are the safety margins used, are the parameters used valid, are they incomplete, strength of evidence used from laboratory studies and field studies, number of 'expert judgments'.

(c) Use of information related to analogous substances

206. If data on climate change impact is not available for the chemical under review, consideration should be given to data on climate change impact on analogous substances if relevant and available.

207. Substances that are structurally similar with physicochemical, toxicological, ecotoxicological and/or environmental fate properties that are likely to be similar or to follow a regular pattern may be considered as analogous substances. These similarities may be due to a number of factors:

• Common functional group (i.e. chemical similarity within the group)
• Common precursors and/or likely common breakdown products via physical and/or biological processes which result in structurally-similar degrading chemicals
• A constant pattern in the properties across the group (i.e. of physico-chemical, toxicological, ecotoxicological, environmental fate properties, ecological and/or biological properties)

208. The analogous substances identity, phase or form, physiochemical profile, similarities and potential differences related to the factors listed in paragraph 207 with the chemical under review should be documented, together with a justification of using the information. If relevant the mode of action and metabolic pathway in organisms should also be included.

7. Key findings

7.1. Conclusions

209. Based on the findings by the United Nations Environment Programme (UNEP)/Arctic Monitoring and Assessment Programme (AMAP) expert group (2011), the predicted interactions between the impacts of climate change and persistent organic pollutants are important to consider when assessing new persistent organic pollutants.

210. The approach in the evaluation of interactions between the chemical under review and climate change can be based on the systematically narrative review and methodology used by POPRC at present. In addition to this background document a simplified approach with a step by step guidance are developed for guidance. There will be no need for developing other special tools or models.

211. The scientific approach traditionally used by the Persistent Organic Pollutants Review Committee is able to handle the uncertainties and ranges of change in physicochemical and biological processes related to the climate change impacts on and interactions with persistent organic pollutants in an adequate manner. In the evaluation of a new persistent organic pollutant in the screening and risk profile stages, it is preferable to use scientific data with given uncertainties for the specific chemical being evaluated. It is considered in the guidance, however, that data on analogous substances can be used where scientifically supportable.

212. The climate change interactions with persistent organic pollutants do not change the intrinsic properties of persistent organic pollutants. The interactions should therefore only be taken into account when considering the risks posed by chemicals. The relevant information should be presented and concern may be raised in the statement of reasons of concern according to paragraph 2 of Annex D.

213. When the Committee considers elements related to "hazard assessment for the endpoints of concern" (Annex E (b)) the evaluation of the interactions between climate change and persistent organic pollutants will be particularly relevant. This also applies for the consideration of "environmental fate" in Annex E (c). There are, however, no parameters in the two criteria (b) and (c) in Annex E clearly addressing climate change interactions with persistent organic pollutants.

214. Multiple stressors are relevant for the hazard assessment under Annex E (b). There are, however, no parameters in the two criteria (b) in Annex E clearly addressing the multiple stressors.

215. The importance of considering multiple stressors, including climate change, when evaluating the risk of hazardous substances, is highlighted by the UNEP/AMAP expert group. Several findings from the Arctic show that the vulnerability of organisms to persistent organic pollutants depends on multiple stress factors, including exposure

to multiple hazardous substances and climate-change-related effects. This highlights the importance of careful scientific consideration of all environmental stress factors, including toxicological interactions and climate change impacts, when conducting the hazard assessment in the risk profile.

216. In the review of new persistent organic pollutants regional differences in climate change as observed and projected by the Intergovernmental Panel on Climate Change should be taken into account.

217. Climate change is predicted by the UNEP/AMAP expert group (2011) to increase the mobilization within (for example, mobilization of sequestered persistent organic pollutants in sea ice, permafrost and glaciers) and transport of persistent organic pollutants to the Arctic and other remote regions. Climate change is also predicted to exacerbate the adverse effects of persistent organic pollutants by increasing temperatures and changing water salinities (UNEP/AMAP, 2011). This may be particularly relevant for the areas in subtropical and tropical regions that have been observed to experience increased salinities and temperatures due to climate change (IPCC 2007c).

218. In addition, extreme weather events such as flooding and heat waves have been observed more frequently in Europe, Australia and developing countries (IPCC 2007c,UNEP/AMAP 2011), as discussed in the chapter 4 draft guidance and are projected to increase with climate change (IPCC 2007c). This could have implications for the management of contaminated areas, stockpiles and waste. Compared to the Arctic, however, there is limited information, especially from developing countries, on persistent organic pollutants and their interactions with climate change in other regions.

219. Along with the recommendations by the UNEP/AMAP expert group (2011) it is also considered important to explore and assess opportunities for co-benefits and mitigation measures to reduce emissions of greenhouse gasses and persistent organic pollutants through appropriate life-cycle management options and relevant regulations when evaluating the impacts of mitigation activities for candidate persistent organic pollutants in the development of a global risk management evaluation (Annex F). In Annex F, the criterion on "movement towards sustainable development" (c) (v) in Annex F) captures the considerations on mitigation activities for candidate persistent organic pollutants and their impact on greenhouse gas emissions.

220. To ensure that the complex climate change interactions with persistent organic pollutants identified in all regions are incorporated into the Committee's review processes for new persistent organic pollutants, further efforts and guidance to enable developing countries to participate effectively in those processes are needed. This is particularly important as climate change impacts will be different in magnitude and variability in different regions. If developing countries are not assisted, therefore, some effects may not be addressed in a timely manner.

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GLOSSARY

Bioconcentration is the process by which the chemical enters an aquatic organism and/or is adsorbed on to it as a result of exposure to the chemical in water, but does not include uptake in the diet. Bioconcentration refers to a condition usually achieved under laboratory conditions where the chemical is taken up directly from the water (UNEP/POPS/POPRC.1/10/ Annex III).

Bioconcentration is described by a bioconcentration factor (BCF), ideally under steady state conditions: BCF = C_B/C_w, where C_B is the concentration of the substance in the whole aquatic organisms, expressed as a whole body fresh weight value, and C_w is the concentration of the substance in water(UNEP/POPS/POPRC.1/10/ Annex III).

Bioaccumulation is the process by which the chemical enters an aquatic or terrestrial organism as a result of chemical uptake through all possible routes of exposure (e.g., dietary absorption, dermal absorption, respiratory uptake). Bioaccumulation is normally measured in field situations or under complex experimental conditions(UNEP/POPS/POPRC.1/10/ Annex III).

Bioaccumulation in aquatic organisms can be expressed in the form of a bioaccumulation factor (BAF), which is the ratio of the chemical concentration in the organism (C_B), expressed as a whole body fresh weight value, to that in water, ideally under steady state conditions (C_w): BAF = $C_B/C_{w.}$ (UNEP/POPS/POPRC.1/10/ Annex III)

Biomagnification is the process by which chemical concentrations increase with trophic level in a food chain. For organic substances, concentrations are normally expressed on a lipid normalized basis. Biomagnification results from the trophic level transfer of a chemical through the diet from a lower to a higher trophic level (UNEP/POPS/POPRC.1/10/ Annex III).

Given the great variability in approaches to calculating the biomagnification factor (BMF), the potential for biomagnification should be used instead of BMF for the evaluation of the bioaccumulation criterion. If a biomagnification potential is identified, it should be considered as a specific concern in the evaluation of criteria 1 © (ii) and (iii) (UNEP/POPS/POPRC.1/10/ Annex III).

Homeostasis is the property of a system that regulates its internal environment and tends to maintain a stable, constant condition of parameters such as temperature or pH. It can be either an open or closed system (Bernard 1929).

Homeothermy is thermoregulation that maintains a stable internal body temperature regardless of external influence.

Homeotherm is an organism that can maintain a stable internal body temperature regardless of external influence.

Photolytic degradation is degradation by photolysis.

Photolysis Bond cleavage induced by ultraviolet, visible, or infrared radiation. (OECD 2008)

Total solar irradiance is defined as the amount of radiant energy emitted by the sun over all wavelengths that fall each second on 11 sq ft (1 sq m) outside the earth's atmosphere. This Solar Irradiance hits the surface of the earth in two forms, beam (Gb) and diffuse (Gd). The beam component comes directly as irradiance from the sun, while the diffuse component reaches the earth indirectly and is scattered or reflected from the atmosphere or cloud cover. http://www.oilgae.com/ref/glos/solar_irradiance.html

Poikilotherm is an organism that must either operate well below optimum efficiency most of the time, migrate, hibernate or expend extra resources producing a wider range of enzymes to cover the wider range of body temperatures.

Transformation products refers to all substances resulting from biotic or abiotic transformation reactions of a chemical. (OECD 2008)

Annex I Annex D in the Convention

INFORMATION REQUIREMENTS AND SCREENING CRITERIA

1. A Party submitting a proposal to list a chemical in Annexes A, B and/or C shall identify the chemical in the manner described in subparagraph (a) and provide the information on the chemical, and its transformation products where relevant, relating to the screening criteria set out in subparagraphs (b) to (e):

(a) Chemical identity:

(i) Names, including trade name or names, commercial name or names and synonyms, Chemical Abstracts Service (CAS) Registry number, International Union of Pure and

Applied Chemistry (IUPAC) name; and

(ii) Structure, including specification of isomers, where applicable, and the structure of the chemical class;

(b) Persistence:

(i) Evidence that the half-life of the chemical in water is greater than two months, or that its half-life in soil is greater than six months, or that its half-life in sediment is greater than six months; or

(ii) Evidence that the chemical is otherwise sufficiently persistent to justify its consideration within the scope of this Convention;

(c) Bio-accumulation:

Evidence that the bio-concentration factor or bio-accumulation factor in aquatic

species for the chemical is greater than 5,000 or, in the absence of such data, that the log Kow is greater than 5;

(ii) Evidence that a chemical presents other reasons for concern, such as high bio-accumulation in other species, high toxicity or ecotoxicity; or

(iii) Monitoring data in biota indicating that the bio-accumulation potential of the chemical is sufficient to justify its consideration within the scope of this Convention;

(d) Potential for long-range environmental transport:

(i) Measured levels of the chemical in locations distant from the sources of its release that are of potential concern;

(ii) Monitoring data showing that long-range environmental transport of the chemical, with the potential for transfer to a receiving environment, may have occurred via air, water or migratory species; or

(iii) Environmental fate properties and/or model results that demonstrate that the chemical has a potential for long-range environmental transport through air, water or migratory species, with the potential for transfer to a receiving environment in locations distant from the sources of its release. For a chemical that migrates significantly through the air, its half-life in air should be greater than two days; and

(e) Adverse effects:

(i) Evidence of adverse effects to human health or to the environment that justifies consideration of the chemical within the scope of this Convention; or

(ii) Toxicity or ecotoxicity data that indicate the potential for damage to human health or to the environment.

2. The proposing Party shall provide a statement of the reasons for concern including, where possible, a comparison of toxicity or ecotoxicity data with detected or predicted levels of a chemical resulting or anticipated from its long-range environmental transport, and a short statement indicating the need for global control.

3. The proposing Party shall, to the extent possible and taking into account its capabilities, provide additional information to support the review of the proposal referred to in paragraph 6 of Article 8. In developing such a proposal, a Party may draw on technical expertise from any source.

Annex II Risk profile outline

Executive summary

1. Introduction

1.1 Chemical identity of the proposed substance

- Mention which Party has made the proposal and when it was made
- Spell out the specific chemical identity and particular considerations related to that identity

1.2 Conclusion of the Review Committee regarding Annex D information

- "The Committee has evaluated Annex D information (add reference to the meeting and the decision) and has concluded that […]"

1.3 Data sources

- Short overview of the data sources provided by the proposing Party or used by the Committee in Annex D screening
- Short overview of data submitted by Parties and observers (NB: a more elaborated summary of the submissions may be provided as a separate POPRC/INF document)
- Information on availability of national and international assessment reports;

1.4 Status of the chemical under international conventions

2. Summary information relevant to the risk profile

2.1 Sources

- Production, trade, stockpiles
- Uses
- Releases to the environment

2.2 Environmental fate

- Further elaboration of information referred to in Annex D, paragraphs (b)-(d), based on all relevant and available information
- Available monitoring data and data on levels of exposure must be integrated under the subheading or alternatively dealt with under separate headings.
- Could be divided into the following categories:

2.2.1 Persistence
2.2.2 Bioaccumulation
2.2.3 Potential for long-range environmental transport

2.3 Exposure

- Summary of relevant information concerning exposure in local areas (both near the source and in remote areas)
- Summary of relevant information concerning exposure as a result of long-range environmental transport
- Information on bioavailability

2.4 Hazard assessment for endpoints of concern

- Further elaboration of information referred to in Annex D, paragraph (e); based on all relevant available information
- Monitoring data on effects included

3. Synthesis of information

- Synthesis of information relevant to the risk profile, in the form of a risk characterization, with emphasis on information that leads to the conclusive statement

4. Concluding statement

- Is the chemical likely, as a result of long-range environmental transport, to cause significant adverse effects on human health or the environment, such that global action is warranted?

References

Note: No annexes; all other data to be provided as POPRC/INF documents.

Target size: not longer than 20 pages.